NASA News

National Aeronautics and
Space Administration

Washington, D.C. 20546
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Press Kit

Project VOYAGERS 1 and 2

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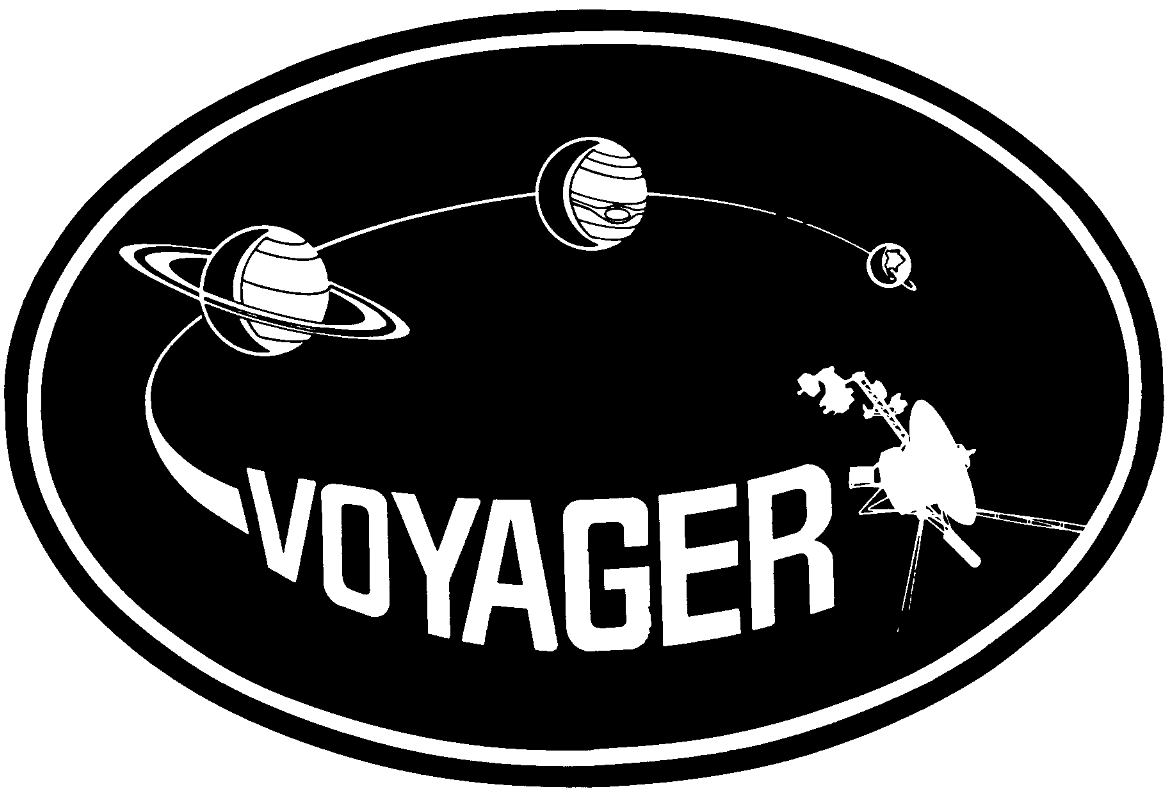

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Nicholas Panagakos
Headquarters, Washington, D.C.
(Phone: 202/755-3680)

12:00 Noon, EDT
THURSDAY,
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Frank Bristow
NASA Jet Propulsion Laboratory, Pasadena, Calif.
(Phone: 212/354-5011)

RELEASE NO: 77-136

TWO VOYAGERS SET FOR LAUNCH

NASA will launch two Voyager spacecraft this summer for an extensive reconnaissance of the outer planets.

Riding atop a Titan Centaur rocket, the Voyagers will be launched from Kennedy Space Center, Fla., on a decade-long odyssey that could take them to as many as 15 major heavenly bodies.

These include giant Jupiter and ringed Saturn, several moons of both planets and possibly Uranus.

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Making measurements and taking closeup pictures, the Voyagers will return information that could shed new light on the origin and early history of the solar system and our own planet Earth.

The first Voyager will be launched about Aug. 20. The second is scheduled for launch 12 days later, about Sept. 1.

Voyager 2 will be launched first and Voyager 1 second, as Voyager 1 will fly a faster trajectory than its companion and reach Jupiter in March, 1979, four months ahead of Voyager 2. At Saturn encounter Voyager 1 will be about nine months ahead of its sister craft.

At Jupiter the gravity-assist technique -- using a planet's gravitational field to speed up a spacecraft and change its trajectory -- will be used to send the Voyagers on to Saturn. With this "slingshot" technique Voyager 1 will arrive at Saturn in late summer of 1980, 3.2 years after launch. Without using Jupiter's massive gravity, the flight from Earth would require 6.1 years. When it reaches Saturn, Voyager will have traveled 2.2 billion kilometers (1.4 billion miles) through space.

After completing their planetary missions, the two spacecraft will continue outward from the solar system and across the boundary of the wind of charged particles (solar wind) that streams outward from the Sun, thus penetrating into interstellar space.

The Voyager spacecraft are advanced versions of planetary explorers that have studied Mercury, Venus and Mars. The new craft weigh 825 kilograms (1,820 pounds). The spacecraft differ from their Mariner and Viking predecessors in many respects, due primarily to the environment into which they will venture and the great distances across which they must communicate with Earth. Since the amount of sunlight which strikes the outer planets is only a small fraction of that which reaches Earth, the Voyagers cannot depend on solar energy but must use nuclear power -- radioisotope thermoelectric generators. The Voyagers are dominated by the largest communications antennas yet flown on planetary missions: 3.7 meters (12 feet) in diameter.

The Voyagers are more automatic and independent of Earth-based control than earlier planetary spacecraft. The great distances across which radio signals between Earth and Voyagers must travel and the long lifetime of the mission require that the Voyagers be able to care for themselves and perform long, detailed and complex scientific surveys without continual commanding from the ground.

They are the first planetary spacecraft to carry an expendable solid-fueled propulsion module for use during launch. After launch, a 68,000-newton-thrust (15,300-lb.-thrust) solid-propellant rocket motors on the propulsion modules will place the spacecraft on their flight paths to Jupiter.

They will use steering thrusters for trajectory corrections. Some trajectory correction maneuvers will require engine burns of more than an hour -- in some cases spread over several days.

Each Voyager will use 11 instruments including the spacecraft radio to study the planets, their satellites, the rings of Saturn, the magnetic regions surrounding the planets and interplanetary space. The instrument payload weighs 105 kg (231 lb.).

The Voyagers will carry wide-angle and narrow-angle television cameras, cosmic ray detectors, infrared spectrometers and radiometers, low-energy charged-particle detectors, magnetometers, photopolarimeters, planetary radio astronomy receivers, plasma and plasma wave instruments and ultraviolet spectrometers.

The television cameras will provide pictures of Jupiter and Saturn of greater resolution than any taken from Earth or by the earlier Pioneer 10 and 11 spacecraft. They will study Jupiter for eight months. The cameras should also take the first high resolution, closeup photos of the Galilean satellites of Jupiter, the major satellites of Saturn and Saturn's rings. (Pioneer 11 is now on a trajectory which will take it through Saturn's rings in 1979, but the pictures taken -- if any -- will have less resolution than the Voyager images by a factor of 100.)

The other Voyager instruments will study the atmosphere of the planets and their satellites, their magnetosphere and the relationships between these regions and the solar wind that streams through interplanetary space and the radio signals from Jupiter (which emits the strongest radio noise in our sky except the Sun). Other objectives include all-sky surveys of interplanetary space and gravitational fields.

An option is being maintained to send Voyager 2 on to the planet Uranus, 20 times farther from the Sun than Earth. Encounter, which would occur in January 1986, would permit the first closeup examination of its recently discovered rings. The Uranus option will be exercised only if primary goals of Saturn have been met by the first Voyager and the operating condition of the second Voyager warrants the added four-year trip.

The Voyager spacecraft receive a large increase in velocity as a result of their close flyby of the planet Jupiter. This gravity-assist velocity increase allows the spacecraft to reach Saturn in the relatively short time of 3.2 to 4 years with a launch vehicle that is only slightly larger than required for Jupiter missions. This opportunity to send a spacecraft to Saturn following a close flyby of Jupiter occurs approximately every 20 years. The opportunity for the Uranus option is the result of the alignment of Jupiter, Saturn and Uranus which happens only once every 45 years.

Project Voyager represents the next step in the United States' program of systematic planetary exploration in which the solar system is used as a natural laboratory. By being able to compare the similarities and differences of the various planets, scientists expect to learn more about the processes that affect the Earth and better understand the history of the solar system.

Until recently our knowledge of Jupiter and Saturn was only rudimentary. Ground-based studies by optical infrared and radio astronomy defined the most basic properties of Jupiter and Saturn and their satellites and hinted at the unique scientific potential of these systems.

In 1973 and 1974 a first close-up look at Jupiter and its system was provided by two Pioneer spacecraft. As Pioneers 10 and 11 sped past Jupiter, their instruments began to reveal the complexity of its atmosphere and the extent and strength of the Jovian magnetosphere. Voyager is the next logical step in the exploration of the Jovian system. Also, by carrying out detailed exploration of Saturn, these spacecraft will provide a fascinating perspective for detailed comparisons of a host of unfamiliar worlds.

Jupiter and Saturn are the largest planets. Together with their many satellites they dominate the solar system. The diameter of Jupiter is 10 times that of Earth, and it contains more matter than all of the other planets put together. With its retinue of 13 moons, four of them as large as planets, Jupiter is actually the center of a miniature solar system like the Sun and planets.

Saturn also has a system of many satellites and includes, in addition, two unique features, a spectacular ring system which appears to be composed mainly of tiny pieces of ice and snow and one large satellite, Titan, with an atmosphere as massive as that of the Earth. In any program of planetary exploration study of the Jovian and Saturnian systems is of paramount interest for understanding the origin and evolution of the solar system.

In spite of their great size, Jupiter and Saturn are mysterious worlds. Both are giant balls of gas with no apparent solid surface. Both are composed largely of hydrogen and helium. These planets best represent the original materials from which the Sun and all the planets -- including Earth -- were formed. Both Jupiter and Saturn constitute minature but uniquely accessible laboratories for study of phenomenon of wide-ranging astrophysical interest.

Like the stars, Jupiter and Saturn each have their own internal energy sources, radiating nearly twice as much energy as they receive from the Sun. As Pioneer 10 and 11 measurements revealed, Jupiter has a strong magnetic field and is surrounded by radiation belts similar to the Van Allen belts around the Earth. The vast, rapidly spinning magnetosphere and radiation belts of Jupiter make it a major source of several types of radio radiation.

The atmospheres of these giant planets are driven by the same forces that act on Earth's atmosphere, but on a much larger scale. Major cyclones, like the Great Red Spot of Jupiter, are thousands of miles across and persist for centuries. Their atmospheres contain multiple cloud layers each with their own temperature and chemical composition.

The four largest satellites of Jupiter, Io, Europa, Ganymede and Callisto, provide a varying and fascinating microcosm of unique worlds. Some are composed largely of rock, some of ice, some of water. Their surfaces probably range from lunar-like cratered plains, to salt-covered beds of extinct seas, to exotic landforms created out of ice and mud. In ice and water-dominated regimes, familiar geologic processes will take place thousands of times faster than on a rocky planet. Totally unfamiliar geologic forms are expected as well. Most satellites of Saturn are apparently also composed primarily of ice. But Titan, the largest satellite in the solar system, has in addition an atmosphere similar in size to that of the Earth's but very different in composition.

Scientists expect that organic molecules are being created today in the atmosphere of Titan and that this strange, cold satellite may even provide clues to the origin of life on Earth.

The three spectacular rings that surround Saturn may be the remains of a satellite that came too close and was broken up by the strong tidal forces of the planet or they may be remnants of material from the birth of the solar system that never coalesced to form a large moon.

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Jupiter orbits the Sun at a distance of 778 million km (483 million mi.). One Jupiter year equals 11.86 Earth years. Jupiter's day is less than 10 hours long.

Saturn orbits the Sun at a distance of 1.42 billion km (883 million mi.). It completes one orbit every 29.46 Earth years. A day on Saturn is 10 hours and 14 minutes long. The widest visible ring of Saturn has a radius of 136,000 km (84,500 mi.).

Closest approach to Jupiter -- March 5, 1979 -- will be about 278,000 km (173,000 mi.) from the visible cloud surface of the planet. Both Earth and Sun will disappear behind Jupiter, as seen from the spacecraft (occultation), allowing scientists to make new measurements of the structure and composition of the planet's upper atmosphere from atmospheric effects on Voyager's radio signals as they pass through the Jovian atmosphere enroute to Earth.

After passing Jupiter, Voyager 1 will examine all four of the large Galilean satellites. Observations of Jupiter will continue for a month after closest approach, until early April 1979.

Voyager 2 will begin its observatory phase of Jupiter about two weeks later, 80 days before closest approach as did Voyager 1. It will observe four satellites during the inbound leg: Callisto, Ganymede, Europa and Amalthea.

The spacecraft will make its closest approach to Jupiter on July 10, 1979. Following a more distant course than its predecessor, the second Voyager will pass more than twice as far from the planet, 643,000 km (400,000 mi.) away. The second Jupiter encounter will continue into August.

The first Saturn encounter will begin in August 1980 and will continue through December. On the inbound leg, Voyager 1 will pass within 4,000 km (2,500 mi.) of the major satellite Titan. Closest approach to Saturn -- 138,000 km (85,800 mi.) -- will occur Nov. 12, 1980. Titan, Saturn and the rings will all block out the Sun and Earth as seen by instruments on the spacecraft to provide occultation measurements.

Second Saturn encounter will begin in June 1981. Closest approach will occur Aug. 27, 1981. Voyager 2 will observe the satellites Titan, Rhea and Tethys on its inbound journey and Enceladus at closest approach. Encounter will continue through September.

Tracking and data acquisition will be performed by the Deep Space Network (DSN) with stations in California, Australia and Spain. At planet encounter, high-rate data will be received through the DSN's 64-m (210-ft.) antenna subnet. Maximum data rate at Jupiter will be 115,000 bits per second, at Saturn 44,800.

NASA's Office of Space Science has assigned Voyager project management to the Jet Propulsion Laboratory (JPL), Pasadena, Calif., which is managed for NASA by the California Institute of Technology. NASA program manager is Rodney Mills and the JPL project manager is John Casani. Dr. Milton A. Mitz is NASA program scientist and Dr. Edward C. Stone of Caltech is project scientist.

JPL designed, assembled and tested the Voyager spacecraft.

Voyager's solid rocket motor is provided by the NASA Goddard Space Flight Center's Delta Office. Prime contractor is Thiokol Chemical Corp.

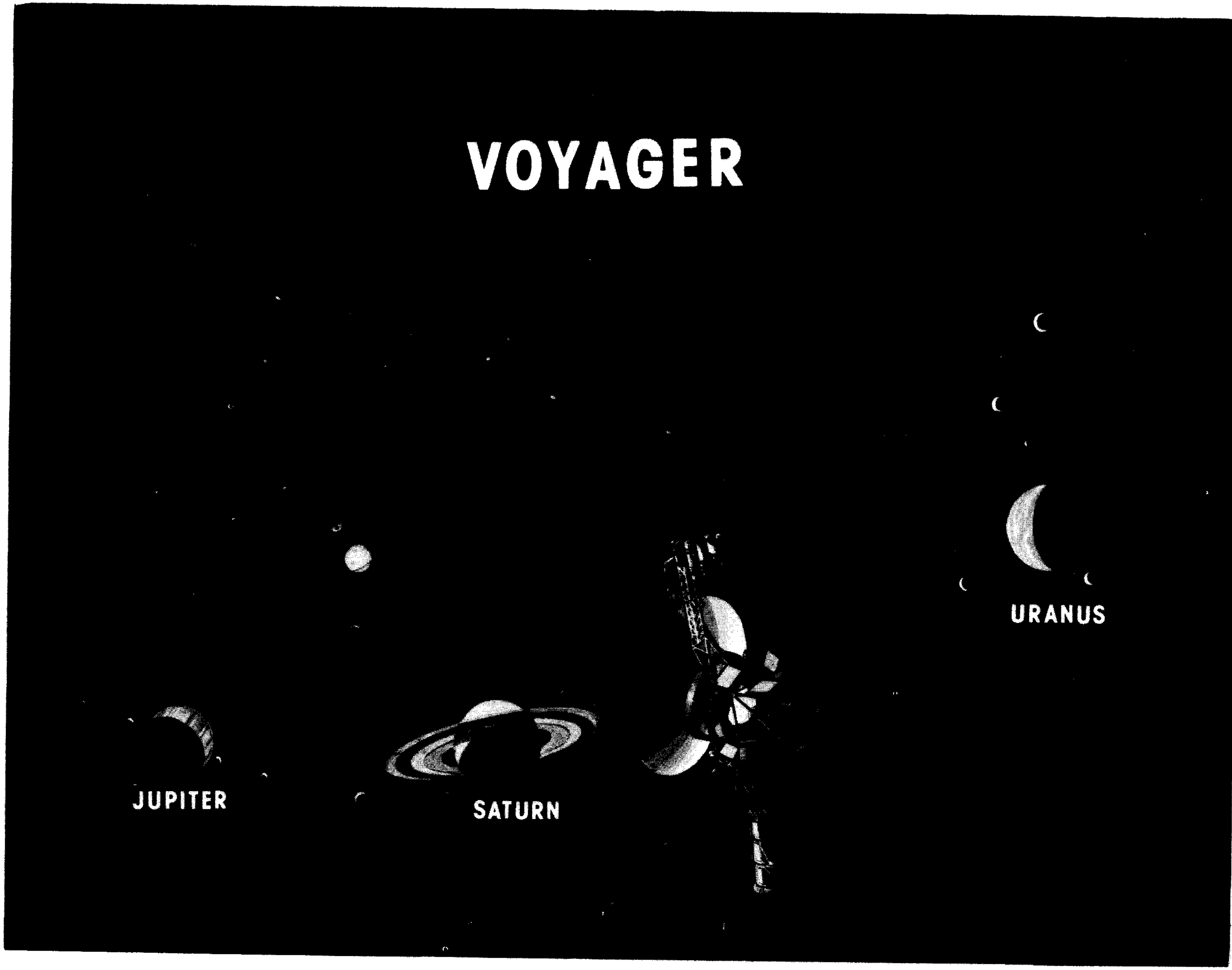
Launch vehicle responsibility has been assigned to NASA's Lewis Research Center, Cleveland, Ohio. Prime contractors to Lewis are Martin Marietta Corp., Denver, Colo., (the Titan) and General Dynamics/Convair, San Diego, Calif., (the Centaur).

Tracking, communications and mission operations are conducted by JPL, which operates the Deep Space Network for NASA's Office of Tracking and Data Acquisition.

The spacecraft's radioisotope thermoelectric generators are provided to NASA by the U.S. Energy Research and Development Administration (ERDA). Prime contractor to ERDA is General Electric Co., Valley Forge, Pa.

Estimated cost of the Voyager project, exclusive of launch vehicles, tracking and data acquisition and flight support activities is $320 million.

(END OF GENERAL RELEASE. BACKGROUND INFORMATION FOLLOWS.)


VOYAGER
JUPITER
SATURN
URANUS

THE VOYAGER SPACECRAFT

The two Voyager spacecraft are designed to operate at distances from Earth and the Sun greater than those of any previous mission. Communications capability, hardware reliability, navigation and temperature control are among the major challenges. The spacecraft are identical. Each can meet the objectives of either mission and their various options.

Each Voyager consists of a mission module -- the planetary vehicle -- and a propulsion module, which provides the final energy increment necessary to inject the mission module into the Jupiter transfer trajectory. The propulsion module is jettisoned within minutes after the required volocity is attained. (For purposes of mission description, "spacecraft" and "mission module" will be used interchangeably. In describing the prelaunch configuration and launch phase, "spacecraft" will refer to the combined "mission module" and "propulsion module.")

The mission module after injection weighs 825 kg (1,820 lbs.), including a 105 kg (231 lb.) science instrument payload. The propulsion module, with its large solid propellant rocket motor, weighs 1,220 kg (2,690 lbs.). The spacecraft adaptor joins the spacecraft with the Centaur stage of the launch vehicle. It weighs 47.2 kg (104 lbs.) Total launch weight of the spacecraft is 2,100 kg (4,630 lbs.).

To assure proper operation for the four-year flight to Saturn, and perhaps well beyond, mission module subsystems have been designed with high reliability and extensive redundancy.

Like the Mariners that explored the inner planets and the Viking Mars Orbiters, the Voyagers are stabilized on three axes using the Sun and a star (Canopus) as celestial reference points.

Three engineering subsystems are programmable for on-board control of spacecraft functions. (only trajectory correction maneuvers must be enabled by ground command.) These subsystems are the computer command subsystems (CCS), the flight data subsystem (FDS) and the attitude and articulation control subsystem (AACS).

The memories of these units can be updated or modified by ground command at any time.

Hot gas jets provide thrust for attitude stabilization as well as for trajectory correction maneuvers.

A nuclear power source -- three radioisotope thermoelectric generators -- provides the spacecraft electrical power.

The science instruments required to view the planets and their moons are mounted on a two-axis scan platform at the end of the science boom for precise pointing. Other body-fixed and boom-mounted instruments are aligned for proper interpretation of their measurements.

Data storage capacity on the spacecraft is about 536 million bits of information -- the equivalent of about 100 full-resolution photos.

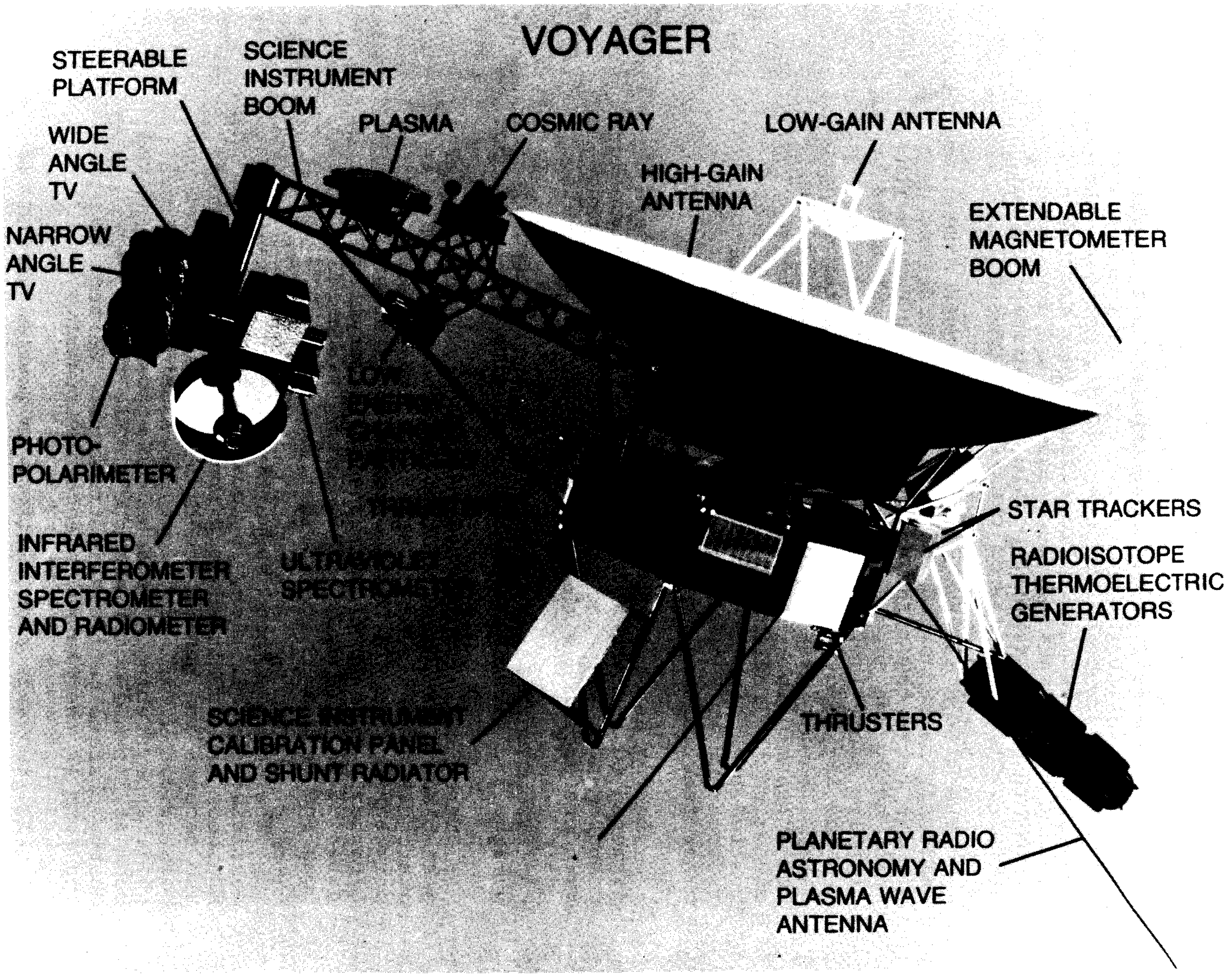
Dual frequency communication links -- S-band and X-band -- provide accurate navigation data and large amounts of science information during planetary encounter periods (up to 115,200 bits per second at Jupiter and 44,800 bps at Saturn).

Dominant feature of the spacecraft is the 3.66-meter (12-foot) diameter high-gain antenna which will point toward Earth continually after the initial 80 days of flight.

While the high-gain antenna dish is white, most visible parts of the spacecraft are black -- blanketed or wrapped for thermal control and micrometeoroid protection. A few small areas are finished in gold foil or have polished aluminum surfaces.

Structure and Configuration

The basic mission module structure is a 29.5 kg (65 lb.) 10-sided aluminum framework with 10 electronics packaging compartments. The structure is 47 centimeters (18.5 inches) high and 1.78m (5.8 ft.) across from side to side. The electronics assemblies are structural elements of the 10-sided box.



VOYAGER
STEERABLE PLATFORM
SCIENCE INSTRUMENT BOOM
PLASMA
COSMIC RAY
LOW-GAIN ANTENNA
HIGH-GAIN ANTENNA
EXTENDABLE MAGNETOMETER BOOM
WIDE ANGLE TV
NARROW ANGLE TV
PHOTO-POLARIMETER
INFRARED INTERFEROMETER SPECTROMETER AND RADIOMETER
ULTRAVIOLET SPECTROMETER
STAR TRACKERS
RADIOISOTOPE THERMOELECTRIC GENERATORS
SCIENCE INSTRUMENT CALIBRATION PANEL AND SHUNT RADIATOR
THRUSTERS
PLANETARY RADIO ASTRONOMY AND PLASMA WAVE ANTENNA

The spherical propellant tank, which supplies fuel to hydrazine thrusters for attitude control and trajectory correction maneuvers (TCM), occupies the center cavity of the decagon. Propellant lines carry hydrazine to 12 small attitude control and four TCM thrusters on the mission module and to larger thrust vector control engines on the propulsion module.

The 3.66 m (12 ft.) diameter high-gain parabolic reflector is supported above the basic structure by a tubular trusswork. The antenna reflector has an aluminum honeycomb core and is surfaced on both sides by graphite epoxy laminate skins. Attachment to the trusses is along a 1.78 m (70 inch) diameter support ring. The Sun sensor protrudes through a cutout in the antenna dish. An X-band feed horn is at the center of the reflector. Two S-band feed horns are mounted back-to-back with the X-band sub-reflector, transparent at S-band, to the high-gain dish. The other functions as the low-gain antenna.

Louver assemblies for temperature control are fastened to the outer faces of four of the electronics compartments. Top and bottom of the 10-sided structure are enclosed with multi-layer thermal blankets.

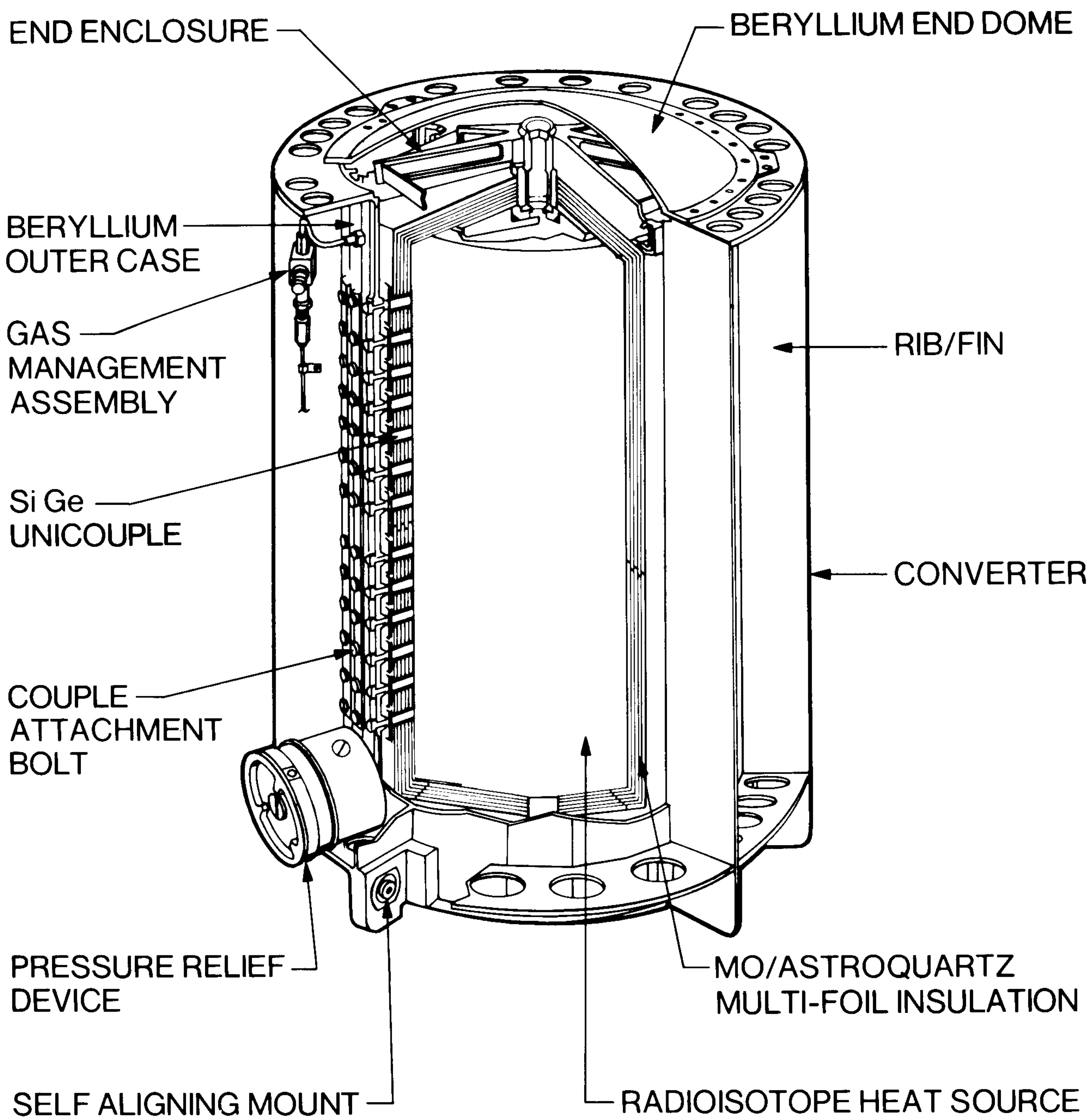
Two Canopus star tracker units are mounted side-by-side and parallel atop the upper ring of the decagon.

Three radioisoptope thermoelectric generators are assembled in tandem on a deployable boom hinged on an outrigger arrangement of struts attached to the basic structure. The RTG boom is constructed of steel and titanium. Each unit, contained in a beryllium outer case, 40.6 cm(16 in.) in diameter, 50.8 cm (20 in.) long and weighs 39 kg (86 lb.).

The science boom, supporting the instruments most sensitive to radiation, is located 180 degrees from the RTG boom and is hinged to a truss extending out from the decagon and behind the high-gain antenna. The boom, 2.3 m (7 1/2 ft.) long, is a bridgework of graphite epoxy tubing. Attached on opposite sides of the boom at its mid-point are the cosmic ray and low-energy charged particle instruments. Farther out on the boom is the plasma science instrument.

The two-axis scan platform is mounted at the end of the boom and provides precision pointing for four remote-sensing instruments -- the ultraviolet spectrometer, infrared spectrometer and radiometer,

VOYAGER RADIOISOTOPE THERMOELECTRIC GENERATOR



photopolarimeter and a two-camera imaging science subsystem. Total platform gimballed weight is 107 kg (236 lb.).

With both the RTG and science booms deployed, the nearest boom-mounted instrument to a radiation source is 4.9 m (16 ft.), with the bulk of the spacecraft between the two. The closest platform-mounted instrument 6.7 m (21 ft.) away.

A polarimetric calibration target, called a brewster plate, is mounted atop the mission module structure and aligned so that the photopolarimeter views the target during science maneuvers planned for the planetary phases of the mission.

A pair of 10 m (33 ft.) whip antennas are deployed from a position external to the top ring of the basic structure and looking "down" between the RTG boom outrigger members. The antennas, which form a right angle, are part of the planetary radio astronomy (PRA) instrument package and are shared with another instrument, the plasma wave science unit (PWS). The PRA and PWS assemblies are body-mounted adjacently. The antennas, beryllium copper tubing, are rolled flat in their housing prior to deployment by small electric motors.

The magnetic fields investigation experiment consists of an electronics subassembly located in one of the mission module electronics bays and four magnetometers -- two high-field sensors affixed to the spacecraft and two low-field sensors mounted on a 13m (43 ft.) deployable boom. The boom, constructed of epoxy glass, spirals from its stowed position within an aluminum cylinder and forms a rigid triangular mast with one magnetometer attached to its end plate and another positioned 6 m (20 ft.) closer to the spacecraft. The mast itself weighs only 2.3 kg (5 lbs.), less than the cabling running its length and carrying power to and data from the magnetometers. The boom housing is a 23 cm (9 in.) diameter cylinder, 66 cm (26 in.) long, supported by the RTG outrigger. The mast uncoils in helix fashion along a line between the rear face of the high-gain antenna and the RTG boom.

Basic structure of the propulsion module is a 44 kg (97 lb.) aluminum semi-monocoque shell.

The cylinder 1 m (39 in.) in diameter and 0.9 m (35 in.) long, is suspended below the mission module structure by an eight-member tubular truss adapter. The hollow of the structure contains the solid rocket motor which delivers the final powered stage of flight. The rocket, which weighs 1,220 kg (2,690 lb.) including 1,060 kg (2,340 lb.) of propellant, develops an average 68,000 N (15,300 lb.) thrust during its 43-second burn.

Mounted on outriggers from the structure are eight hydrazine engines to provide attitude control during the solid motor burn and prior to propulsion module separation and jettison. Hydrazine fuel is supplied from the mission module.

A pair of batteries and a remote driver module for powering the valve drivers to the thrust vector control engines are positioned on the outer face of the cylindrical propulsion module structure.

A 0.37 sq. m (4 sq. ft.) shunt radiator-science calibration target faces outward from the propulsion module truss adapter toward the scan platform. The dual-purpose structure is a flat sandwich of two aluminum radiating surfaces lining a honeycomb core. Through an arrangement of power collectors and emitter resistors between the plates, any portion of the electrical power from the RTGs can be radiated to space as heat. The outer surface also serves as a photometric calibration target for the remote sensing science instruments on the scan platform.

The shunt radiator, as well as the propulsion module truss adapter, remain part of the mission module when the propulsion module is jettisoned.

Steel alloy-gold foil plume deflectors extend from the propulsion module structure to shield the stowed RTGs and scan platform from rocket exhaust during engine firing.

The spacecraft adapter, an aluminum truncated cone, joins the propulsion module with the Centaur stage of the launch vehicle. The adapter, 0.71 m (30 in.) tall, 1.6 m (63 in.) in diameter at the base (Centaur attachment), 1.0 m (39 in.) at the spacecraft separation joint and weighs 47.2 kg (104 lb.). The adapter remains with the Centaur rocket stage.

Launch Configuration

Some mechanical elements of the spacecraft must be rigidly restrained during the severe launch vibration environment. Following the launch phase appendages which were latched securely within the Centaur stage nose fairing are deployed to their cruise positions.

The spacecraft pyrotechnic subsystem provides simple and positive deployment with explosive squibs. Devices stowed securely during launch and released for deployment by the pyrotechnic system are the science boom, RTG boom and magnetometer boom.

The pyrotechnic subsystem also routes power to devices to separate the spacecraft from the launch vehicle, activates the propulsion module batteries, ignites the solid propellant rocket motor, seals off the propellant line carrying hydrazine from the mission module to the propulsion module, jettisons the propulsion module and releases the Infrared Radiometer and Interfermeter Spectrometer insrument-s dust cover.

Communications

Communications with the Voyager spacecraft will be by radio link between Earth tracking stations and a dual frequency radio system aboard the spacecraft.

The "uplink" operates at S-band, carrying commands and ranging signals from ground stations to one of a pair of redundant receivers. The "downlink" is transmitted from the spacecraft at S-band and X-band frequencies.

The onboard communications system also includes a programmable flight data subsystem (FDS), modulation demodulation subsystem (MDS), data storage subsystem (DSS) and high gain and low gain antennas.

The FDS, one of the three onboard computers, controls the science instruments and formats all science and engineering data for telemetering to Earth. The telemetry modulation unit (TMU) of the MDS feeds data to the downlink. The flight command unit of the MDS routes ground commands received by the spacecraft.

Only one receiver will be powered at any one time with the redundant receiver at standby. The receiver will operate continuously during the mission at about 2113 MHz. Different frequency ranges have been assigned to the radio frequency subsystems of each spacecraft. The receiver can be used with either the high gain or low gain antenna.

The S-band transmitter consists of two redundant exciters and two redundant RF power amplifiers of which any combination is possible. Only one exciter-amplifier combination will operate at any one time. Selection of the combanation will be by onboard failure detection logic within the computer command subsytem (CCS), with ground command backup. The same arrangement of exciter-amplifier combinations makes up the X-band transmitting unit.

One S-band and both X-band amplifiers employ traveling wave tubes (TWT). The second S-band unit is a solid-state amplifier. The S-band transmitter is capable of operating at 9.4 watts or at 28.3 watts when switched to high power and can radiate from both antennas. X-band power output is 12 watts and 21.3 watts. X-band uses only the high gain antenna. (S-band and X-band will never operate at high power simultaneously).

When no uplink signal is being received, the transmitted S-band frequency of about 2295 MHz and X-band frequency of 8418 MHz originate in the S-band exciter's auxiliary oscillator or in a separate ultra stable oscillator (one-way tracking). With the receiver phase-locked to an uplink signal, the receiver provides the frequency source for both transmitters (two-way tracking). The radio system can also operate with the receiver locked to an uplink signal while the downlink carrier frequencies are determined by the onboard oscillators (two-way noncoherent tracking).

At present, only the 64-m (210-ft.) antenna stations of the Deep Space Network can receive the downlink X-band signal. Both the 64-m and the 26-m (85-ft.) antenna stations are capable of receiving at S-band.

The X-band downlink will not be in use during about the first 80 days of the mission -- until the Earth is within the beam of the spacecraft's high gain antenna.

Communications during launch, near-Earth and early cruise phase operations will be confined to S-band and the low gain antenna. An exception occurs during the first week of flight when the spacecraft, on inertial control, points the high gain antenna toward Earth to support instrument calibration and an optical navigation high-rate telecommunications link test.

The high gain antenna, with a 3.66-m-diameter (12 ft.) parabolic reflector, provides a highly directional beam. The low gain antenna provides essentially uniform coverage in the direction of Earth.

Under normal conditions after the first 80 days of the mission, all communications -- both S-band and X-band -- are via the high gain antenna. X-band is turned off, however, and the S-band transmitter and receiver are switched to the low gain antenna during periodic science maneuvers and trajectory correction maneuvers.

The S-band downlink is always on, operating at high power during maneuvers or during the cruise phase only when the 26 m (85 ft.) antenna DSN stations are tracking low power whenever X-band is on. At Saturn, both S-band and X-band transmitters will be at low power when gyros and tape recorder are on simultaneously.

Commanding the Spacecraft

Ground commands are used to put into execution selected flight sequences or to cope with unexpected events. Commands can be issued in either a predetermined timed sequence via onboard program control or directly as received from the ground. Most commands will be issued by the spacecraft's computer command subsystem (CCS) in its role as "sequencer of events" and by the flight data subsystem (FDS) as controller of the science instruments.

All communications between spacecraft and Earth will be in digital form. Command signals, transmitted at 16 bits per second (bps) to the spacecraft, will be detected in the flight command unit and routed to the CCS for further routing to their proper destination. Ground commands to the spacecraft fall into two major categories: discrete comands and coded commands.

A discrete command causes a single action on the spacecraft. For example, DC-2D switches the S-band amplifier to high power; DC-2DR, S-band amplifier low power; DC-2E, S-band radiates from high gain antenna; DC-2ER, S-band transmits low gain. Coded commands are the transfer of digital data from the computer command system or from the ground via the CCS to user subsystems. Subsystems receiving coded commands are flight data, attitude and articulation control, modulation-demodulation, data storage and power.

Ground commands back up all critical spacecraft functions which, in a standard mission, are initiated automatically by onboard logic. Command modulation will be off during science maneuvers and trajectory correction maneuvers unless a spacecraft emergency arises.

Downlink Telemetry

Data telemetered from the spacecraft will consist of engineering and science measurements prepared for transmission by the flight data subsystem, telemetry modulation unit and data storage subsystem. The encoded information will indicate voltages, pressures, temperatures, television pictures and other values measured by the spacecraft telemetry sensors and science instruments.

Two telemetry channels -- low rate and high rate -- are provided for the transmission of spacecraft data. The low rate channel functions only at S-band at a single 40 bits per second data rate and contains real time engineering data exclusively. It is on only during planetary encounters when the high rate channel is operating at X-band.

The high rate channel is on throughout the mission, operates at either S-band or X-band and contains the following types of data:

- Engineering only at 40 bps or 1,200 bps (the rate usually occurs only during launch and trajectory correction maneuvers) transmitted at S-band only.

- Real-time cruise science and engineering at 2,560, 1,280, 640, 320, 160 and 80 b.p.s. (40, 20 and 10 bps may be used for post-Saturn operations) transmitted at S-band only.

- Real time encounter general science and engineering at 7.2 kilobits per second (a special 115.2 kbps rate will be available for brief periods at Jupiter for the planetary radio astronomy and plasma wave instruments) transmitted at X-band only.

- Real time encounter general science, engineering and television at 115.2, 89.6, 67.2, 44.8, 29.9, and 19.2 kbps transmitted at X-band only.

- Real time encounter general science and engineering, plus tape recorder playback, at 67.2, 44.8 and 29.9 kbps transmitted at X-band only.

- Play back recorded data only at 21.6 and 7.2 kbps transmitted at X-band only.

- Memory data stored in the three onboard computers -- CCS, FDS and AACS -- read out and played back at 40 or 1,200 bps transmitted at either S-band or X-band (treated as engineering data).

The numerous data rates for each type of telemetered information are required by the changing length of the telecommunications link with Earth and the possible adverse effects of Earth weather upon reception of X-band radio signals. The S-band cruise science primary telemetry rate is 2,560 bps. Lesser rates result in reduced instrument sampling and will be used only when the telecommunications link cannot support the higher rate.

In order to allow real time transmission of video information at each encounter, the flight data subsystem will handle the imaging data at six downlink rates from 115.2 to 19.2 kbps. The 115.2-kbps rate represents the standard full frame readout at 48 seconds per frame) of the TV vidicon. Under normal conditions, this rate will be used at Jupiter. Full frame, full resolution TV from Saturn can be obtained by increasing the frame readout time to 144 seconds (3:1 slow scan) and transmitting the data at 44.8 kbps a number of other slow scan and frame edit options are available to match the capability of the telecommunications link.

The data storage subsystem can record at two rates: TV pictures, general science and engineering at 115.2 kbps; general science and engineering only at 7.2 kbps (engineering is acquired at only 1,200 b.p.s., but is formatted with filler to match the recorder input rate). The tape transport is belt driven. Its 1/2-inch magnetic tape is 328 m (1,075 ft.) long and is divided into eight tracks which are recorded sequentially one track at a time. Total recycleable storage capacity is about 536 million bits -- the equivalent of 100 TV pictures. Playback is at four speeds -- 57.6, 33.6, 21.6 and 7.2 kbps.

Tracking the Spacecraft

To achieve the desired maneuver and flyby accuracies for a multi-planet/satellite encounter mission, very precise navigation is required.

To provide the standard Doppler tracking data, the S-band signal transmitted from Earth is received at the spacecraft, changed in frequency by a known ratio and retransmitted to Earth. It is possible to precisely determine the transmitted downlink frequency while measuring the Doppler shifted received signal, thereby measuring spacecraft velocity. This is called coherent two-way tracking. One-way tracking is when no uplink signal is received and the downlink carrier frequency is provided by an onboard oscillator. Noncoherent two-way tracking occurs when uplink and downlink carriers are operating independently.

(When both S-band and X-band transmitters are on, X-band frequency will always be 11/3 times the S-band frequency regardless of the frequency source -- spacecraft receiver, ultra stable oscillator or S-band exciter auxiliary oscillator.)

Distance or range to the spacecraft is measured in the coherent two-way configuration by transmitting a digital code (ranging modulation) on the uplink, turning this code around in the spacecraft and sending it back to the ground. By measuring the total elapsed time between transmitting and receiving the code at the ground station and knowing such factors as the speed of light, turnaround delay and relative velocities of the spacecraft and tracking station, it is possible to determine spacecraft range.

Dual frequency ranging (both S-band and X-band ranging on) will be conducted during planetary operations phases of the mission and during the cruise phases when the Deep Space Network's 64-m (210-ft. antennas are tracking. Special three-way dual-frequency ranging cycles will be conducted while two or more ground stations on two continents are tracking the spacecraft.

All ranging modulation is turned off during science maneuvers, trajectory correction maneuvers and planetary occultations.

Power

The Voyager power subsystem supplies all electrical power to the spacecraft by generating, converting, conditioning and switching the power.

Power source for the mission module is an array of three radioisotope thermoelectic generators (RTGs), developed by the U.S. Energy Research and Development Administration (ERDA). The propulsion module, active only during the brief injection phase of the mission, uses a separate battery source.

The RTG units, mounted in tandem on a deployable boom and connected in parallel, convert to electricity the heat released by the isotopic decay of Plutonium-238.

Each isotope heat source has a capacity of 2400 thermal watts with a resultant maximum electrical power output of 160 watts at the beginning of the mission. There is a gradual decrease in power output. The minimum total power available from the three RTGs ranges from about 423 watts within a few hours after launch to 384 watts after the spacecraft passes Saturn.

Spacecraft power requirements from launch to post-Saturn operations are characterized by this general power timeline: launch and post-launch, 235 to 265 watts; interplanetary cruise, 320 to 365 watts; Jupiter encounter, 384 to 401 watts; Saturn encounter, 377 to 382 watts; and post-Saturn, less than 365 watts.

Telemetry measurements have been selected to provide the necessary information for power management by ground command, if needed.

The RTGs will reach full power about six to eight hours after launch. During prelaunch operations and until about one minute after liftoff, the generator interiors are kept filled with an inert gas to prevent oxidation of its hot components. Venting the generators to space vacuum is achieved with a pressure relief device actuated when the outside ambient pressure drops below 10 psia.

Power from the RTGs is held at a constant 30 volts d.c. by a shunt regulator. The 30 volts is supplied directly to some spacecraft users and is switched to others in the power distribution subassembly. The main power inverter also is supplied the 30 volts d.c. for conversion to 2.4 kHz square wave used by most spacecraft subsystems. Again, the a.c. power may be supplied directly to users or can be switched on or off by power relays.

Command actuated relays control the distribution of power in the spacecraft. Some relays function as simple on-off switches and others transfer power from one module to another within a subsystem.

Among the users of d.c. power, in addition to the inverter, are the radio subsystem, gyros, propulsion isolation valves, some science instruments, most temperature control heaters and the motors which deploy the planetary radio astronomy antennas.

Other elements of the spacecraft use the 2.4 kHz power.

There are two identical 2.4 kHz power inverters -- main and standby. The main inverter is on from launch and remains on throughout the mission. In case of a malfunction or failure in the main inverter, the power chain, after a 1.5-second delay is switched automatically to the standby inverter. Once the switch-over is made, it is irreversible.

A 4.8 kHz sync and timing signal from the flight data subsystem is used as a frequency reference in the inverter. The frequency is divided by two and the output is 2.4 kHz plus-or-minus 0.002 per cent. This timing signal is sent, in turn, to the computer command subsystem which contains the spacecraft's master clock.

Because of the long mission lifetime, charged capacitor energy storage bank are used instead of batteries to supply the short term extra power demanded by instantaneous overloads which would cause the main d.c. power voltage to dip below acceptable limits. A typical heavy transient overload occurs at turn-on of a radio power amplifier.

Full output of the RTGs, a constant power source, must be used or dissipated in some way to prevent overheating of the generator units or d.c. voltage rising above allowed maximum. This is controlled by a shunt regulator which dumps excess RTG output power above that required to operate the spacecraft. The excess power is dissipated in resistors in a shunt radiator mounted outside the spacecraft and radiated into space as heat.

Two batteries independently supply unregulated d.c. power to a remote driver module (RDM) for powering valve drivers to the thrust vector control engines on the propulsion module during the injection phase of the mission. The batteries and the RDM are located in the propulsion module which is jettisoned a few minutes after the mission module is injected onto a Jupiter transfer trajectory. Each battery is composed of 22 silver oxide-zinc cells with a capacity of 1200 ampere seconds at 28 to 40 volts, depending upon the load.

Basic requirement on the batteries is high power for a short period -- 12 minutes. With a lifetime of only 66 minutes the batteries are kept inert until just four seconds before Centaur separation and 20 seconds before solid rocket ignition. After activation, in which an electrolyte is injected into the cells, the batteries are at full voltage in one-half second and ready for use in two seconds.

Computer Command Subsystem

Heart of the onboard control system is the computer command subsystem (CCS) which provides a semi-automatic capability to the spacecraft.

The CCS includes two independent plated wire memories, each with a capacity of 4,096 data words. Half of each memory stores reusable fixed routines which will not change during the mission. The second half is reprogrammable by updates from the ground.

Most commands to other spacecraft subsystems are issued from the CCS memory, which, at any given time, is loaded with the sequences appropriate to the mission phase. The CCS also can decode commands from the ground and pass them along to other spacecraft subsystems.

Under control of an accurate onboard clock, the CCS counts hours, minutes or seconds until some pre-programmed interval has elapsed and then branches into subroutines stored in the memory which result in commands to other subsystems. A sequencing event can be a single command or a routine which includes many commands (e.g. manipulating the tape recorder during a playback sequence).

The CCS can issue commands singly from one of its two processors or in a parallel or tandem state from both processors. An example of CCS dual control is the execution of trajectory correction maneuvers.

TCM thrusters are started with a tandem command (both processors must send consistent commands to a single output unit) and stopped with a parallel command (either processor working through different output units will stop the burn).

The CCS can survive any single internal fault. Each funtional unit has a duplicate elsewhere in the subsystem.

Attitude Control and Propulsion

Stabilization and orientation of the spacecraft from launch vehicle separation until end of the mission is provided by two major engineering subsystems -- attitude and articulation control (AACS) and propulsion.

Propulsion Subsystem

The propulsion subsystem consists of a large solid-propellant rocket motor for final Jupiter transfer trajectory velocity and a hydrazine blowdown system which fuels 16 thrusters on the mission module and eight reaction engines on the propulsion module.

The single hydrazine (N_2H_4) supply is contained within a o.71-m (28-in.) diameter spherical titanium tank separated from the helium pressurization gas by a Teflon filled rubber bladder. The tank, located in the central cavity of the mission module's 10-sided basic structure, will contain 105 kg (231 lb.) of hydrazine at launch and will be pressurized at 2,900,000 newtons/meters^2 (420 psi). . As the propellant is consumed, the helium pressure will decrease to a minimum of about 900,000 newtons/meters^2 (130 psi).

All 24 hydrazine thrusters use a catalyst which spontaneously initiates and sustains rapid decomposition of the hydrazine.

The 16 thrusters on the mission module each deliver 0.89 N (0.2-lb.) thrust. Four are used to execute trajectory correction maneuvers; the others in two redundant six-thruster branches, to stabilize the spacecraft on its three axes. Only one branch of attitude control thrusters is needed at any time.

Mounted on outriggers from the propulsion module are four 445 N-(100-lb.) thrust engines which, during solid-motor burn, provide thrust-vector control on the pitch and yaw axes. Four 22.2-N (5-lb-) thrust engines provide roll control.

The solid rocket, which weighs 1,220 kg (2,690 lb.) including 1,060 kg (2,340 lb.) of propellant, develops an average 68,000 newton (15,300 lb.) thrust during its 43-second burn duration.

Attitude and Articulation Control Subsystem

The AACS includes an onboard computer called HYPACE (hybrid programmable attitude control electronics), redundant Sun sensors, redundant Canopus star trackers, three two-axis gyros and scan actuators for positioning the science platform.

The The HYPACE contains two redundant 4,096-word plated wire memories -- part of which are fixed and part reprogrammable -- redundant processors and input-output driver circuits. For a nominal mission, the memories will be changed only to modify predetermined control instructions.

Injection Propulsion Control

Because of the energy required to achieve a Jupiter ballistic trajectory with an 800 kg (1750 lb.) payload, the spacecraft launched by the Titan III E/ Centaur includes a final propulsive stage which adds a velocity increment of about 7,200 kmps (4,500 mph).

The solid rocket motor in the propulsion module is ignited 15 seconds after the spacecraft separates from the Centaur and burns for about 43 seconds. Firing circuits to the motor are armed during the launch vehicle countdown.

The four 100-lb. thrust engines provide pitch and yaw attitude control and the four 5-lb. thrust engines provide roll control until burnout of the solid rocket motor. The hydrazine engines respond to pulses from the AACS's computer. Only two pitch-yaw and two roll engines at most are thrusting at any given time.

Prior to solid rocket ignition and following burn-out, only the smaller roll engines are required until the propulsion module is separated from the mission module. They are so oriented on the propulsion module that, by proper engine selection by the AACS, attitude control is maintained on all three axes.

Approximately 11 minutes after solid rocket burnout, the propulsion module is jettisoned. Several seconds earlier, the propellant line carrying hydrazine from the mission module to the propulsion module is sealed and separated.

Celestial Reference Control

The Sun sensors, which look through a slot in the high gain antenna dish, are electro-optical devices that send attitude position error signals to HYPACE, which, in turn, signals the appropriate attitude control thruster to fire and turn the spacecraft in the proper direction. Sun lock stabilizes the spacecraft on two axes (pitch and yaw).

The star Canopus, one of the brightest in the galaxy, is the second celestial reference for three-axis stabilization. Two Canopus trackers are mounted so that their lines of sight are parallel. Only one is in use at any one time. The star tracker, through HYPACE logic, causes the thrusters to roll the spacecraft about the already fixed Earth or Sun pointed roll axis until the tracker is locked on Canopus. Brightness of the tracker's target star is telemetered to the ground to verify the correct star has been acquired.

To enhance downlink communications capability, the Sun sensor will be electrically biased (offset) by commands from the computer command subsystem to point the roll axis at or as near the Earth as possible. The Sun sensor can be biased plus and minus 20 degrees in both pitch and yaw axes.

Three axis stabilization with celestial reference is the normal attitude control mode for cruise phases between planets.

- more -

Inertial Reference Control

The spacecraft can be stabilized on one axis (roll) or all three axes with the AACS's inertial reference unit, consisting of three gyros.

Appropriate inertial reference modes are used whenever the spacecraft is not on Sun-star celestial lock. Such situations include: maintaining inertial reference from Centaur separation until initial celestial acquisition is achieved; purposely turning the spacecraft off Sun-star lock to do directed trajectory corrections or science instrument mappings or calibrations; providing a reference when the Sun is occulted; and providing a reference when concern exists that the Canopus or Sun sensor will detect stray intensity from unwanted sources -- planets, rings, satellites.

Each gyro has associated electronics to provide position information about two orthogonal axes (Gyro A: pitch and yaw, Gyro B: roll and pitch, Gyro C: yaw and roll). Normally, two gyros will be on for any inertial mode. The gyros have two selectable rates, one -- high rate -- for propulsion module injection phase; the other for mission module cruise and trajectory correction and science maneuvers.

Trajectory Correction Maneuvers

The Voyager trajectories are planned around eight trajectory correction maneuvers (TCM) with each spacecraft between launch and Saturn encounter. Mission requirements call for extremely accurate maneuvers to reach the desired zones at Jupiter, Saturn and the target satellites. Total velocity increment capability for each spacecraft is about 724 km/hr (450 mph).

The first maneuver is planned for the period from launch plus five days to launch plus 15 days. The burn may take several hours, depending upon launch vehicle and injection phase trajectory errors and may be done in several parts because of thermal constraints at this Sun-spacecraft distance. Subsequent TCMs will not be so constrained. Three more maneuvers will be executed prior to closest approach to Jupiter and four more between Jupiter and Saturn.

TCM sequencing is under control of the computer command subsystem (CCS) which sends the required turn angles to the AACS for positioning the spacecraft at the correct orientation in space and, at the proper time, sends commands to the AACS to start and stop the TCM burn. Attitude control is maintained by pulse-off sequencing of the TCM engines and pulse-on sequencing of two attitude control roll thrusters. Position and rate signals are obtained from the gyros. Following the burn, reacquisition of the cruise celestial references is accomplished by unwinding the commanded turns -- repeating the turn sequence in reverse order. All TCMs are enabled by ground command.

Science Platform (Articulation Control)

Voyager's two television cameras, ultraviolet spectrometer, photopolarimeter and infrared spectrometer and radiometer are mounted on a scan platform which can be rotated about two axes for precise pointing at Jupiter, Saturn and their satellites during the planetary phases of the flight. The platform is located at the end of the science boom. Total gimballed weight is 107 kg (236 lb.).

Controlled by the attitude and articulation control subsystem (AACS), the platform allows multiple pointing directions of the instruments. Driver circuits for the scan actuators -- one for each axis -- are located in the AACS computer. The platform's two axes of rotation are described as the azimuth angle motion about an axis displaced 7 degrees from the spacecraft roll axis (perpendicular to the boom centerline) and elevation angle motion about an axis perpendicular to the azimuth axis and rotating with the azimuth axis. Anglar range is 360 degrees in azimuth and 210 degrees in elevation.

The platform is slewed one axis at a time with selectable slew rates in response to computer command subsystem commands to the AACS. Slew rates are: high rate, 1 degree per second; medium rate; .33 degree /s; low rate; .083 degrees/s; and a special UVS low rate; .0052 degree/s Camera line of sight will be controlled to within 2.5 milliradians.

- more -

Temperature Control

The two Voyager spacecraft are designed to operate farther from Earth than any previous man made object. Survival depends greatly upon keeping temperatures within operating limits while the spacecraft traverses an environmental range of one solar constant at the Earth distance to four per cent of that solar intensity at Jupiter and less than one per cent at Saturn.

Unprotected surfaces at the Saturn range, nearly one billion miles from the Sun can reach 196 C (321 F) below zero -- the temperature of liquid nitrogen.

Both top and bottom of the mission module's basic decagon structure are enclosed with multi-layer thermal blankets to prevent the rapid loss of heat to the cold of space. The blankets are sandwiches of aluminized Mylar, sheets of Tedlar for micrometeroid protection and outer black Kapton covers which are electrically conductive to prevent the accumulation of electrostatic charges.

Also extensively blanketed are the instruments on the scan platform. Smaller blankets and thermal wrap cover eight electronics bays, boom and body-mounted instruments, cabling, propellant lines and structural struts. Only a few exterior elements of the spacecraft are not clad in the black film -- the high gain antenna reflector, plasma sensors, sun sensors and antenna feed cones.

Temperature control of four of the 10 electronics compartments is provided by thermostatically-controlled louver assemblies which provide an internal operating range near room temperature. The louvers are rotated open by bimetallic springs when large amounts of heat are dissipated. These bays contain the power conditioning equipment, the radio power amplifiers, the HYPACE and the tape recorder. Mini-louvers are located on the scan platform, cosmic ray instrument and and the Sun sensors.

Radiodisotope heating units (RHU), small non-power-using heater elements which generate one watt of thermal energy, are located on the magnetometer sensors and the Sun sensors. No RHUs are used near instruments which detect charged particles.

Electric heaters are located throughout the spacecraft to provide additional heat during certain portions of the mission. Many of the heaters are turned off when their respective valves, instruments or subassemblies are on and dissipating power.

MISSION PROFILE

Trajectories for the Voyager flights were chosen not only to give scientists close up looks at the planets but at many important satellites. In fact, Voyager is a mission to more than 15 major bodies in the solar system.

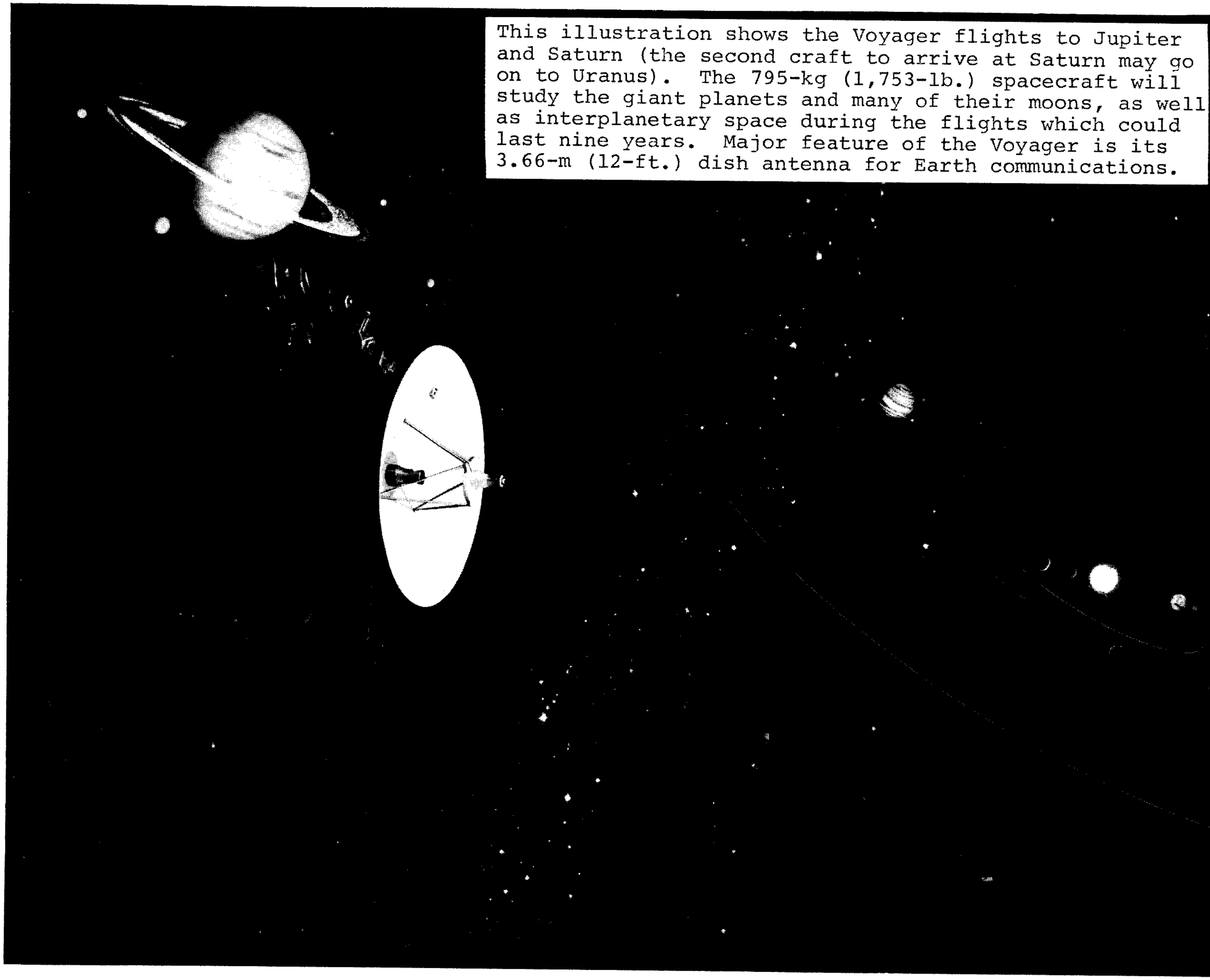
According to the mission plan, Voyager 2 will be launched first. Voyager 1 will fly a faster trajectory and will overtake Voyager 2 before they reach Jupiter. Voyager 1 will arrive at Jupiter four months ahead of Voyager 2 and will be nine months out in front by the time it reaches Saturn.

Each Voyager uses 10 instruments and the spacecraft radio to perform 11 investigations. They will study the two planets, Saturn's rings, at least 11 of their satellites and interplanetary space.

The trajectory for each spacecraft is unique. Computer simulations of many possible flight paths were used for analysis. The final choice will afford maximum coverage of both planets and their major satellites. The spacecraft will make equatorial passes at Jupiter and use the giant planet's gravity to boost them toward Saturn. The Voyagers will get good views of Saturn's polar region, a close fly-by of Titan and will study several of its other satellites at close range. An option exists for the later arriving Voyager -- if everything has gone well and the spacecraft is still healthy -- to fly on to Uranus.

Scientific operations begin soon after launch, when observations of the Earth and Moon will be made. Fields and particles measurements will also commence shortly after launch.

In addition to monitoring the solar wind and related phenomena constantly, each spacecraft will, about every 50 million miles, spin slowly to calibrate instruments and take optical measurements in all directions.



This illustration shows the Voyager flights to Jupiter and Saturn (the second craft to arrive at Saturn may go on to Uranus). The 795-kg (1,753-lb.) spacecraft will study the giant planets and many of their moons, as well as interplanetary space during the flights which could last nine years. Major feature of the Voyager is its 3.66-m (12-ft.) dish antenna for Earth communications.

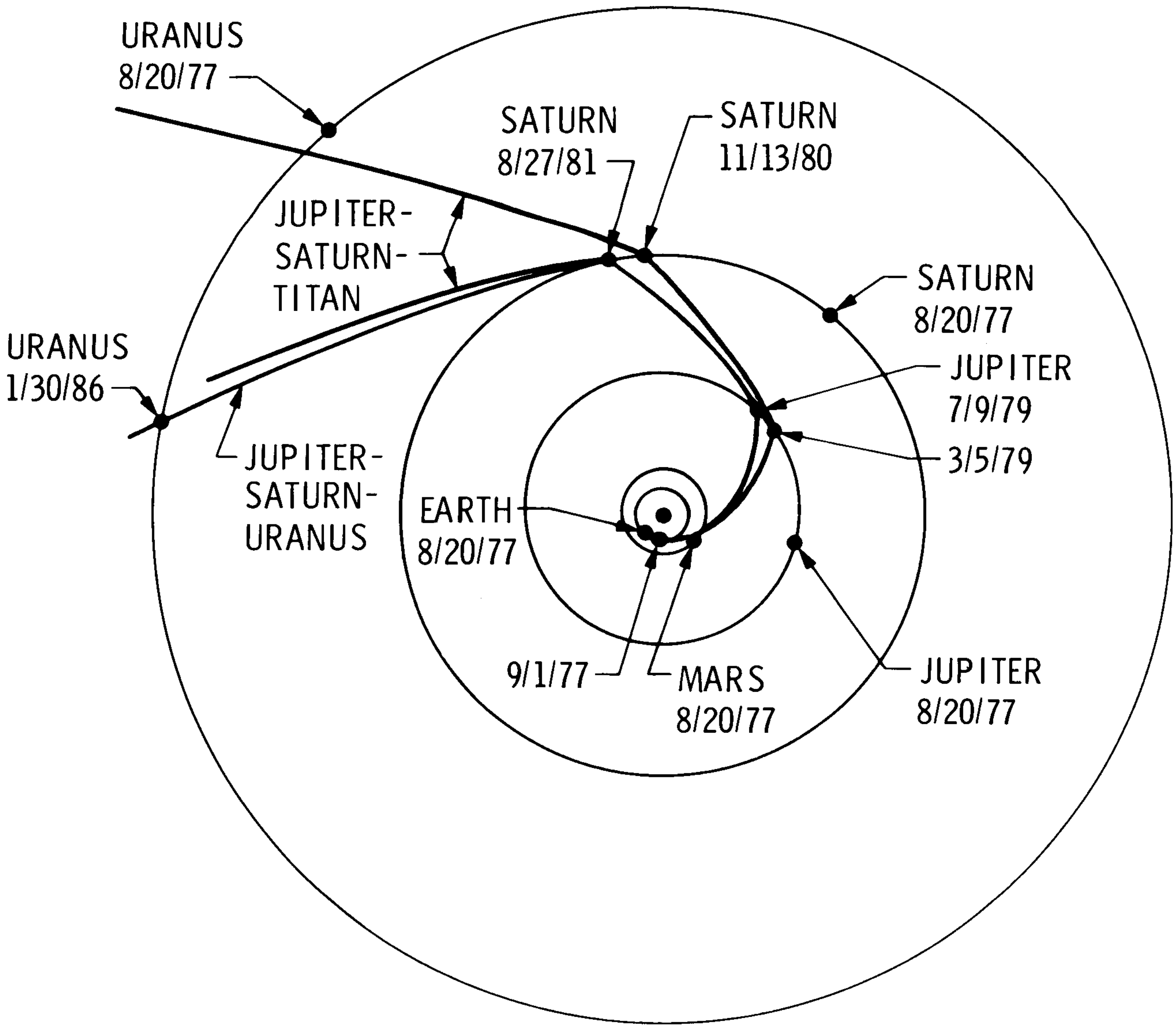
The first Voyager will approach within 80 million km (50 million mi.) of Jupiter on Dec. 15, 1978. At that distance, Jupiter's disc will be large enough so the narrow-angle television camera can begin its "observatory phase" 80 days before closest approach.

The camera will take hundreds of color images of the planet. They will be recorded on the spacecraft's tape recorder and transmitted to Earth daily. Ultraviolet, infrared and polarimetry observations of the visible disc of Jupiter are planned. Magnetic-field, plasma-wave and radio astronomy experiments will make continuous observations of Jupiter and space around it. Charged-particle sensors -- from the plasma detector at the low end of the energy spectrum to the cosmic-ray counter at the high-energy end -- will observe solar phenomena as they search for the boundary of Jupiter's magnetosphere.

On Feb. 5, 1979, when Voyager 1 is 30 days and 30 million km (18.6 million mi.) from Jupiter, the planet will have grown to 2 1/2 times the size it appeared in December. Scanning instruments will produce more pictures, spectra and other measurements. Scientists concerned with Jupiter's atmosphere will select features of special interest -- such as the Great Red Spot and transient storms. Those interested in Jupiter's satellites will prepare for long-range and close-up studies. Scientists who study the magnetosphere, plasma interaction and charged particles around Jupiter will watch for Voyager to cross the boundary between interplanetary space and Jupiter's domain, expected about 10 days before closest approach.

Eighteen days before closest approach, Jupiter will loom too large for the narrow-angle camera to cover in the available time. It will surrender survey duties to the wide-angle instrument. The narrow-angle camera will follow selected features. Spectrometers will scan the atmosphere and cloud tops to help determine the composition and nature of the brilliant bands.

VOYAGER FLIGHT PATHS



Near encounter will occur during the first days of March 1979 (page 44). Activity will reach a peak on-board the spacecraft and at the Mission Control Center at Jet Propulsion Laboratory. Shortly before closest approach to Jupiter -- at 4 a.m. (PST), March 5, 1979 -- Mariner will fly within 415,000 km (258,000 mi.) of Amalthea, innermost of Jupiter's many satellites, giving scientists their first close look at the tiny object.

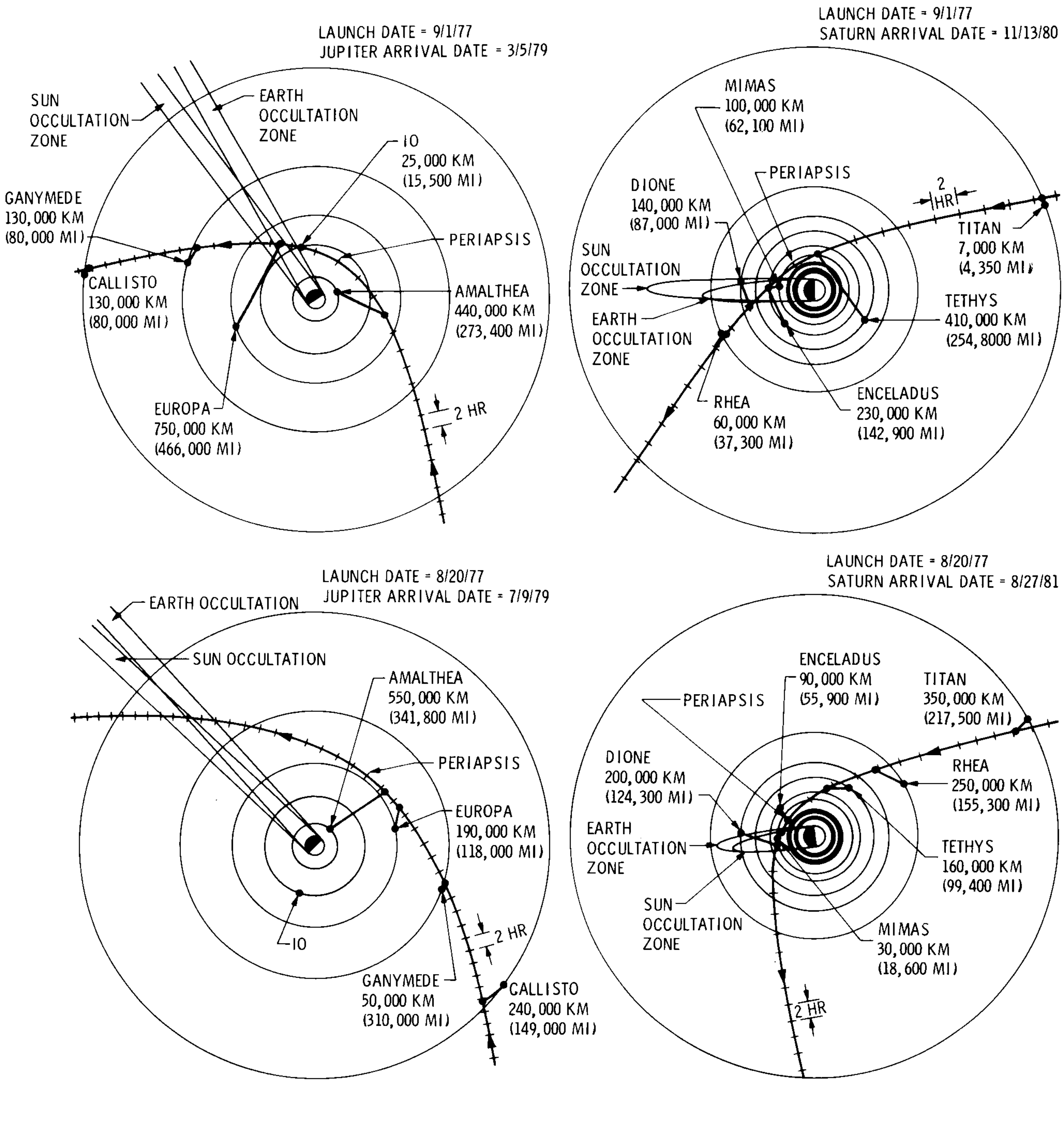
The spacecraft will flash past Jupiter about 278,000 km (173,000 mi.) from the surface of the planet. Then, for almost two hours, controllers will lose contact with Voyager 1 as it is occulted by Jupiter while its on-board computer directs the flight, the data collection by its instruments and recording for later playback to Earth. Following this closest approach to Jupiter and just before the spacecraft enters Jupiter's shadow, the spacecraft will examine Io from 22,000 km (13,700 mi.). As the spacecraft passes Io it will fly through the "flux-tube," a region of magnetic and plasma interaction between Jupiter and Io. Disappearance of the spacecraft behind Jupiter will allow scientists to study the upper atmosphere of the planet as sunlight and the dual-frequency (S-band and X-band) radio links cut off and then reappear.

After passing Jupiter, Voyager 1 will examine three more of the four big Galilean satellites: Europa from 733,000 km (455,000 mi.); Ganymede from 115,000 km (71,500 mi.); and Callisto from 124,000 km (77,000 mi.).

Jupiter's gravity will slingshot Voyager toward Saturn, 750 million km (466 million mi.) farther from the Sun. Voyager will continue to study Jupiter and its satellites until early April, about a month after closest approach.

Planetary operations with the second spacecraft will begin about April 20, 1979. Its observatory phase will continue earlier measurements for a look at the planet that covers more than eight months.

TYPICAL VOYAGER FLYBYS OF JUPITER AND SATURN



To avoid radiation hazards close to Jupiter, the second Voyager will fly about 9 Jupiter radii (643,000 km or 400,000 mi.) from the visible cloud surface. It will not repeat the close flyby of Io. It will survey Callisto from 220,000 km (137,000 mi.) and Ganymede from 55,000 km (34,000 mi.). It will fly within 201,000 km (125,000 mi.) of Europa and will take a quick look at Amalthea. Closest approach to Jupiter will take place July 10, 1979. The remainder of the month and the first week in August will be taken up with outbound observations.

About a year after the Jupiter phase of the mission ends, Voyager 1 will begin its studies of Saturn -- Aug. 24, 1980.

The image of the ringed planet will grow in the narrow-angle camera's field of view through the fall of 1980. By late October, the rings will be too big to be captured in a single frame and it will be necessary to mosaic multiple frames. No one knows how extensive Saturn's magnetosphere is, so the particles and fields instruments will begin continuous high-rate data acquisition a month before the Nov. 12 closest approach.

Plans for the first Voyager call for a flyby within 4,000 km (2,500 mi.) of the southern regions of the major satellite Titan, whose diameter is about 5,800 km (3,600 mi.) and whose mass is about double that of Earth's moon. The spacecraft will fly past Tethys about an hour and a half before it reaches Saturn and then will be occulted both from Earth and the Sun.

Voyager 1 will fly past Saturn's southern hemisphere, about 138,000 km (85,800 mi.) from the center of the planet. Wide-angle and narrow-angle cameras and photometric, ultraviolet and infrared instruments will study Saturn and its rings intensively. The magnetosphere and accompanying regions of trapped charged particles will be charted along the spacecraft's path.

Voyager will lose contact with Earth for a short time -- as it did at Jupiter -- when it passes behind Saturn and the rings. Careful measurement of the radio tracking signals will provide a physical profile deep into the atmosphere and will help scientists explain the nature and structure of the rings.

As the spacecraft flies away from Saturn, surveys of the satellites Enceladus and Rhea are planned and its scan platform will look back at the lighted crescent and tilted rings of Saturn, collecting long-range information for another month.

Six months after the end of the first Saturn encounter, on June 8, 1981, Voyager 2 will move into range. NASA has left options open for the flyby. There are two choices: If all has gone well, with a successful first encounter of Saturn and a healthy second spacecraft, a trajectory may be picked that will boost the second spacecraft toward the planet Uranus. The plan calls for a fairly close pass at Saturn, crossing the plane of the rings about 38,000 km (23,600 mi.) beyond the visible outer edge, giving up a repeat of the close Titan pass. Instead, Titan will come within 353,000 km (219,000 mi.); Rhea 254,000 km (150,000 mi.); Tethys 159,000 km (99,000 mi.); Mimas and Enceladus less than 100,000 km (62,000 mi.); and Dione 196,000 km (122,000 mi.).

Another option is to target for a close encounter with Titan on a similar trajectory as the first spacecraft.

Closest approach to Saturn will occur at 8:50 a.m. (EDT), Aug. 27, 1981. Voyager will finish its observation sequence by the end of September. The two spacecraft will have completed thorough examinations of the two planets and their satellite systems. The quantity of planetary data will exceed that from Mariner 9 in its 11-month survey of Mars in 1970-71, to which may be added several years' worth of fields and particles measurements in the outer solar system. The atmospheres and magnetospheres of the planets will have been analyzed and charted, and five Jovian and six or seven Saturnian satellites surveyed in varying detail.

If the Uranus option is exercised, Voyager will reach the seventh planet from the Sun by Jan. 30, 1986.

Uranus is markedly different from the other gas giants. It is tilted so far on its axis that the poles align almost with the plane of the ecliptic. In relation to the other planets, Uranus rolls along on its side. Every 84 years the Sun shines directly on the north pole; 42 years later the northern hemisphere is dark and the southern pole points sunward. In 1986 the orientation will allow the spacecraft to fly almost vertically through the equatorial and satellite plane. This geometry gives an excellent profile of any magnetosphere and plasma cloud that may be present and an examination of the sunlit hemispheres of Uranus and several of its satellites including its largest, Miranda. Voyager 2 can then fly out through the planet's wake, looking back at the southern hemisphere.

JUPITER

Everything about Jupiter is enormous: when the solar system formed, most of the material that did not end up in the Sun went to make Jupiter. It is larger than the rest of the planets combined.

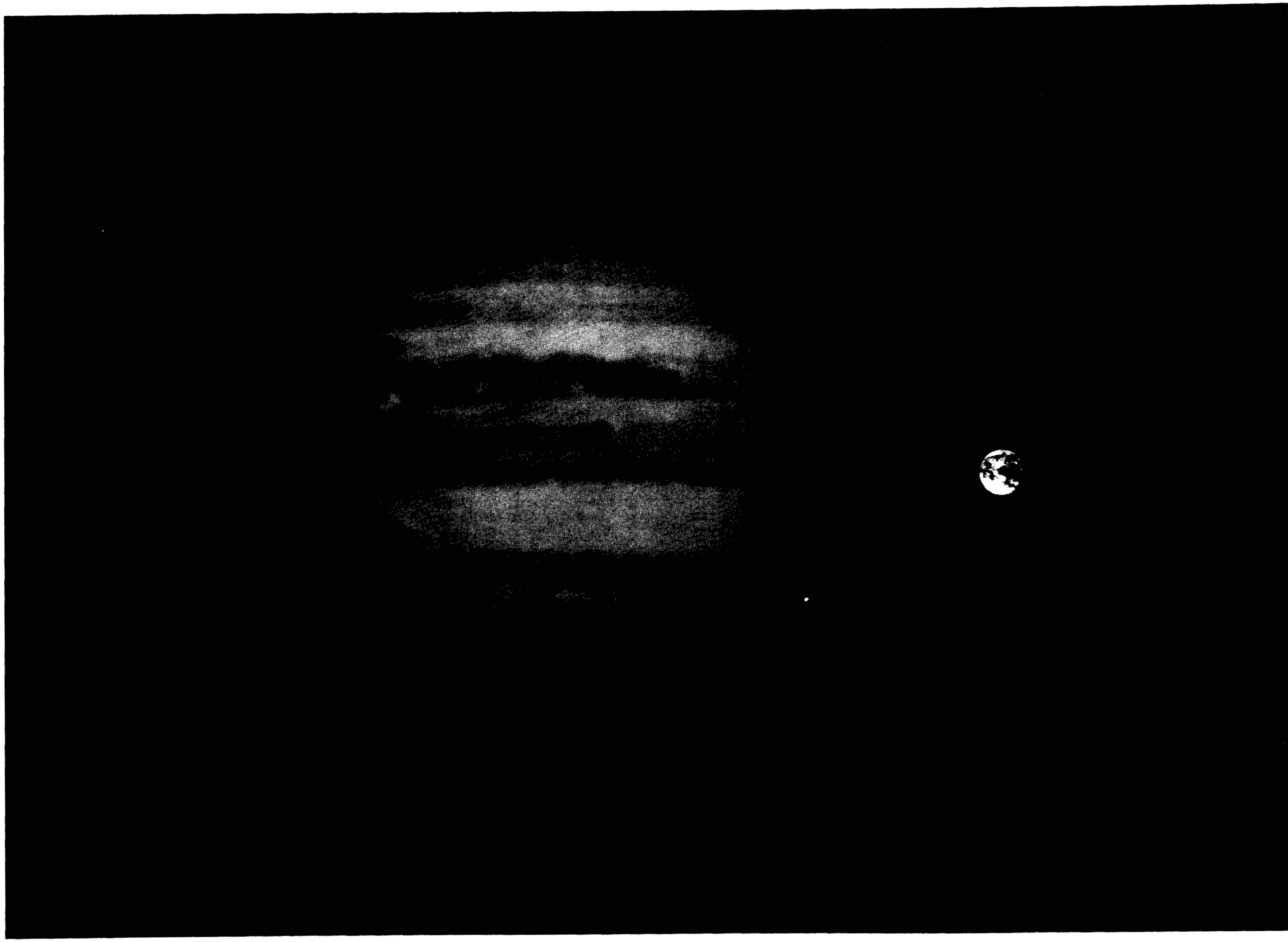
Jupiter is the fifth planet from the Sun. It completes one orbit every 11.86 Earth years.

A day on Jupiter is complete in 9 hours, 55 minutes and 30 seconds. This extremely rapid rotation causes the planet to be flattened at the poles. Equatorial radius is 71,600 km (44,500 mi.), and the polar radius is 67,000 km (42,000 mi.).

Jupiter has 13 known satellites. A 14th may have been seen recently by Charles T. Kowal of Caltech, who also found the 13th in 1974. The four largest satellites were discovered by the first man to aim a telescope at Jupiter -- Galileo Galilei in 1609-10. Galileo's discovery that Jupiter has satellites provided evidence that the Copernican theory of the solar system was correct and that Earth is not the center. The four satellites discovered by Galileo (grouped together and called the Galilean satellites) are Io, Europa, Ganymede and Callisto. They range in size from the planet Mercury to the Moon. All will be studied by the Voyagers.

Jupiter is composed primarily of hydrogen. Indeed it is so massive that very little of its original material could have escaped in the 4.6 billion years or so since it formed. The second most abundant element in Jupiter is helium. The ratio of hydrogen to helium on Jupiter probably is about the same as in the Sun. The solar ratio is roughly one atom of helium for 10 molecules of hydrogen.

Several other substances have been identified spectroscopically in the Jovian atmosphere: ammonia, methane, water, ethane and acetylene. The presence of hydrogen sulfide has been inferred. These are minor components, relative to hydrogen and helium.



Earth and Jupiter to scale.

The currently popular model of Jupiter's structure begins with a small iron silicate core only a few thousand kilometers in diameter. The core is inferred because cosmic abundances of the elements include small amounts of iron and silicates. The temperature there is thought to be about 30,000 degrees Kelvin (54,000 degrees Fahrenheit).

Surrounding the suspected core is a thick layer in which hydrogen is the most abundant element. The hydrogen is separated into two layers, both liquid but in different states. The inner layer, about 46,000 km (29,000 mi.) radius, is liquid metallic hydrogen, which means that the hydrogen is electrically conductive like ordinary metals. That form of hydrogen has not been observed in laboratories since it requires immense heat and pressure. On Jupiter it is thought to exist at temperatures around 11,000 degrees Kelvin (20,000 degrees Fahrenheit) and at pressures about 3 million times Earth's sea-level atmosphere.

The next layer -- liquid hydrogen in its molecular form -- extends to about 70,000 km (44,000 mi.). Above that layer, reaching to the cloud tops for another 1,000 km (600 mi.) is the atmosphere.

If the model is correct, Jupiter has no solid surface, but exists as a rapidly spinning ball of gas and liquid almost 779 million km (484 million mi.) from the Sun.

One of the puzzles about Jupiter is the fact that it radiates about two and a half times the amount of heat that it receives from the Sun. Early models postulated nuclear reactions inside the planet or heat from gravitational contraction. These ideas are no longer believed likely.

Since a liquid is virtually incompressible, however, and since Jupiter is too small and too cold to generate nuclear reactions, scientists now believe the excess heat being radiated by the planet is left over from the primordial heat generated when the planet coalesced out of the solar nebula. As NASA's Dr. John Wolfe writes, "Jupiter cannot be radiating heat because it is contracting; on the contrary, it is contracting because it is slowly cooling."

The visible surface of Jupiter consists of bands of clouds, alternating dark and light, from the equator to about 50 degrees latitude, as shown on page 52 . These bands appear to be convection cells that are stretched by Coriolis forces created by the planet's rapid rotation. By convention, the light features are called zones and the dark ones belts. The light zones appear to be regions of greater altitude and cooler temperatures than the dark belts. Gas warmed by the planet's internal heat rises and cools in the upper atmosphere and forms clouds of ammonia crystals suspended in gaseous hydrogen. At the top of the zones, the cooler material moves toward the equator or the poles, is deflected in an east-west direction by Coriolis forces and then sinks back to lower altitudes. A similar but much smaller mechanism on Earth causes the trade winds.

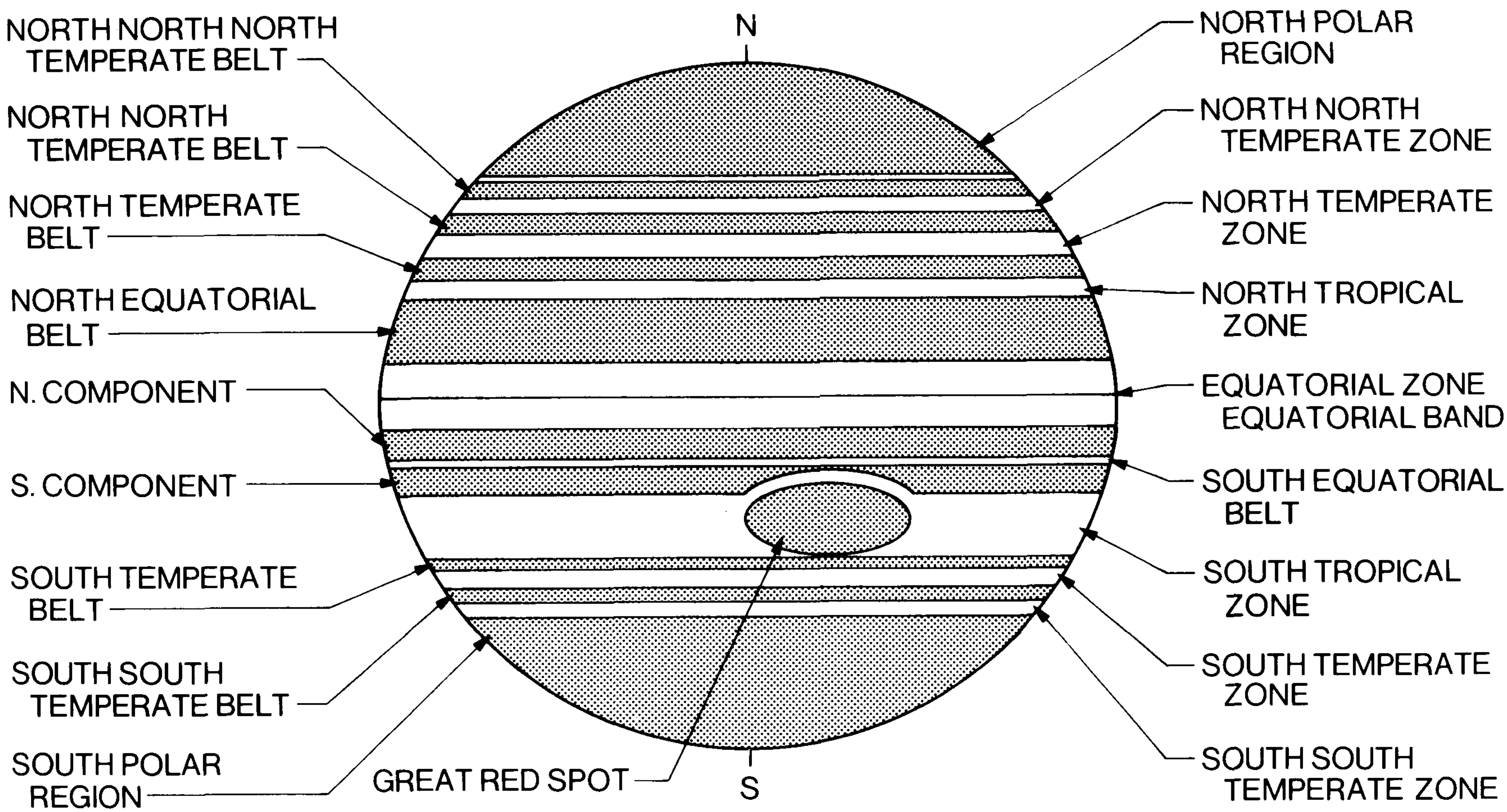
One of the most prominent features on Jupiter is the Great Red Spot. It has been observed almost constantly since its discovery 300 years ago by Giovanni Domenico Cassini. Its width is almost always about 14,000 km (9,000 mi.), but its length varies between 30,000 km (19,000 mi.) and 40,000 km (25,000 mi.).

The Great Red Spot appears to resemble an immense hurricane on Earth -- although it is much larger and has lasted much longer than any terrestrial storms.

Other spots have been observed in the Jovian atmosphere that are similar to but much smaller than the Great Red Spot. They, too, appear in the equatorial regions but have relatively short lifetimes. The one most recently observed lasted just under two years.

Above about 50 degrees latitude, the bands disappear and the Jovian atmosphere becomes turbulent and disorganized. It appears to contain many small convection cells such as those that create the belts and zones of the lower latitudes.

MAJOR FEATURES OF JUPITER



Radio astronomers found evidence for a magnetic field around Jupiter during observations in the 1950s when they discovered radio-frequency emissions coming from the planet. The emissions are confined to two regions of the spectrum -- with wavelengths measured in tens of meters (decametric) and in tenths of meters (decimetric). The decimetric contribution comes primarily from nonthermal mechanisms that depend on the planet's magnetic field. This "synchrotron radiation" comes from electrons that move near the speed of light.

The satellite Io appears to have some link with the decametric radiation, since the bursts seem to occur when Io crosses the face of Jupiter.

While the Jovian magnetic field is essentially dipolar (north and south, like Earth's), its direction is opposite Earth's (the needle of a compass on Jupiter would point south). The axis of the field is offset about 10.8 degrees from the rotational axis and the center of the axis is offset from the center of the planet by about one tenth of a Jupiter radius. At the planet's cloud tops the field ranges between three and 14 gauss (Earth's magnetic field at the surface averages about one half gauss).

The shape of Jupiter's magnetic field is about the same as Earth's with some significant differences. The movement of energetic particles near the equator is intense, but at higher latitudes falls off dramatically. There is apparently an electric-current sheet along the magnetic equator that traps and holds particles there.

The five inner satellites of Jupiter affect distribution of charged particles. As the satellites orbit Jupiter they sweep particles out of their way and at the same time their surfaces are altered by the impinging particles.

Jupiter's outer magnetosphere is highly variable in size, possibly due to changes in the solar-wind pressure. Both Pioneer spacecraft flew in and out of the magnetosphere several times on their inbound legs. The first crossed the magnetopause -- outer edge of the region -- at about 100 Jupiter radii (R_J) and crossed again as close as 50 R_J. Earth's magnetosphere would shrink that much only in the event of the largest solar magnetic storms.

High-energy electrons have also been observed in another unexpected place -- ahead of the bow shock wave in interplanetary space. Scientists believe high-energy particles in Jupiter's magnetosphere reach such velocity that they can escape. Reexamination of records from Earth satellites turned up the fact that these electrons had been observed for many years. They were believed, however, to be of cosmic origin. Now scientists think they spin down the solar magnetic field lines and intersect Earth, since their peaks occur every 13 months when Earth and Jupiter are connected by the spiral lines of the interplanetary magnetic field.

Jupiter's satellites fall into three groups -- the large inner bodies, then a group of four that are small and a final group, also four in number, that are far distant and have retrograde orbits.

The five inner satellites are Amalthea (the smallest, about 240 km or 150 mi. in diameter); Io, larger than Mercury; Europa, Ganymede and Callisto.

Io is about 3,640 km (2,260 mi.) in diameter. It displays some of the most bizarre phenomena in the solar system. The density of Io is about the same as that of the Moon, indicating a rocky composition. Io has a layer of ionized particles about 100 km (60 mi.) above the surface; the satellite has a tenuous atmosphere. Measurements indicate the atmosphere is about one billionth as dense as Earth's. Io is surrounded by a yellow glow -- an ionized cloud of sodium. Also detected in this tenuous extended atmosphere are hydrogen, potassium and sulfur. The surface of this Jovian moon has a unique spectrum, probably due to a combination of sulfur and salts deposited long ago through hydrothermal outgassing. Io also has reddish polar caps of unknown composition.

Europa, smaller than Io, has a diameter of 3,050 km (1,900 mi.). Europa appears to be a rocky body like Io and scientists say this is probably because it heated early in its history to a temperature high enough to drive off the volatiles. However, its white highly reflective surface is almost entirely covered with ice and frost.

Ganymede is one of the largest satellites in the solar system. Its diameter is 5,270 km (3,270 mi.). Ganymede may be mostly liquid water -- a planet-sized drop of water with a mud core and a crust of ice. The surface is not pure ice, however. It is mixed with darker material of unknown composition.

Callisto has a diameter of 5,000 km (3,110 mi.). It is darker than the other Galilean satellites, apparently because of absence of ice or light-colored salts. It may have suffered the least change of all the big satellites since formation billions of years ago. Scientists believe it is probably half water and may contain so little rock that radioactive heating has not melted or differentiated it.

The outer satellites, in order of increasing distance from Jupiter, are: Leda, Himalia, Lysithea, Elara, Ananke, Carme, Gasiphae and Sinope. All the outer satellites appear to be very different from the inner group. They may be former asteroids captured by Jupiter. Or they may be the remains of broken-up satellites. Their orbits are fairly highly inclined (25 to 28 degrees from the equatorial plane) and the outermost four pursue retrograde paths.

SATURN

Saturn is the farthest planet from the Sun known to the ancients. Not until Sir William Herschel discovered Uranus in 1781 did anyone know of the existence of a trans-Saturnian planet.

Saturn is unique in the solar system. It is the only planet less dense than water and, until the recent discovery of Uranus' rings, was thought to be the only planet with rings.

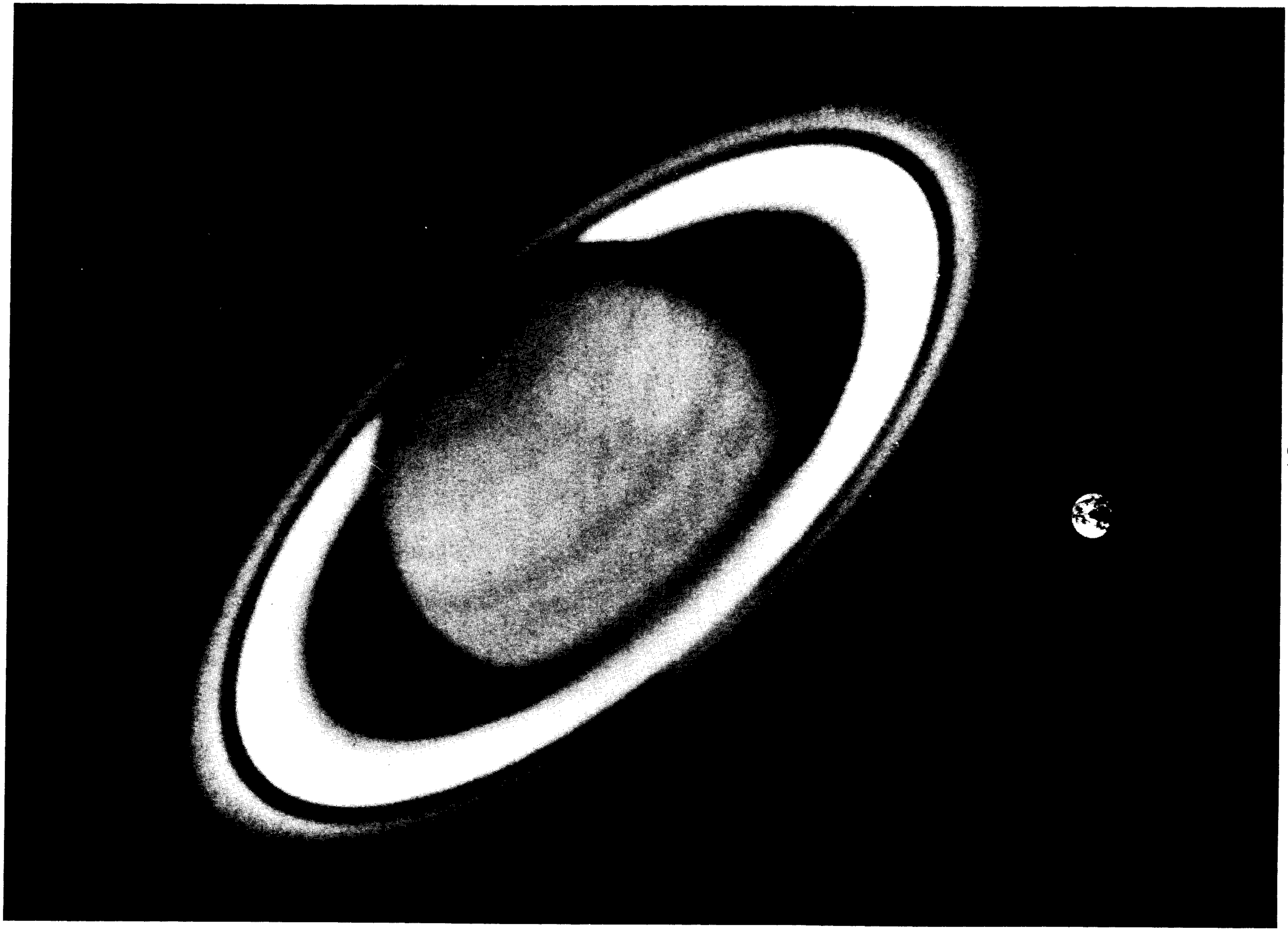
The rings were discovered in 1610 when Galileo Galilei aimed the first astronomical telescope at Saturn. Even Galileo didn't realize what they were. He reported seeing "cup handles" in his less-than-adequate telescope. Forty-five years later, in 1655, Christian Huygens described the rings' true form.

Saturn has a volume 815 times greater than Earth's, but a mass only 95.2 times greater. It is the second largest planet. Saturn's equatorial radius is 60,000 km (37,300 mi.). The polar radius is considerably smaller -- 53,500 km (33,430 mi.). The dynamic flattening, caused by Saturn's rapid rotation and increased by its low density, is the greatest of any planet yet measured.

A day on Saturn's equator is only 10 hours, 14 minutes -- 18.5 minutes longer than a day on Jupiter. Saturn completes one orbit of the Sun in 29.46 Earth years. The average distance of Saturn from the Sun is 9.5 A.U.* Saturn receives only about 1/100th the Sun's intensity that strikes Earth.

Saturn, like the other outer giants, bears some resemblance to Jupiter -- enough that they are often coupled together as the Jovian planets. Like Jupiter, Saturn apparently has no solid surface, but changes gradually from a thin outer atmosphere through progressively denser layers to the core, which may be a small chunk of iron and rock.

*An astronomical unit (A.U.) is the mean distance from the Sun to the Earth -- 149,600,000 km (92,960,000 mi.).



Earth and Saturn to scale.

When scientists discuss the planet's atmosphere, they generally restrict their attention to a region where pressure varies from 1,000 Earth atmospheres to one 10-billionth atmosphere (10^{-10}).

Like Jupiter, the principal constituents of the Saturnian atmosphere are thought to be hydrogen and helium. Three molecules have definitely been detected in Saturn's atmosphere: hydrogen (H_2), methane (CH_4) and ethane (C_2H_6). Radio observations provide indirect evidence for ammonia (NH_3) at atmospheric levels inaccessible to optical measurements. No other molecular or atomic species has been detected.

Also, like Jupiter, Saturn is believed to be composed of materials in about the same ratio as the Sun, formed into the simplest molecules expected in a hydrogen rich atmosphere.

Saturn appears to radiate nearly twice as much energy as it receives from the Sun. In the case of Jupiter, that radiation has been explained as primordial heat left over from the time, about 4.6 billion years ago, when the planet coalesced out of the solar nebula. The same may be true for Saturn. Convection is the most likely transport mechanism to carry heat from the interior of the planet to the surface.

Saturn has cloud bands similar to Jupiter's, although they are harder to see and contrast less with the planetary disc. Photographs confirm that Saturn's bland appearance is real. The blandness may be a result of lower temperatures and reduced chemical and meteorological activity compared with Jupiter or a relatively permanent and uniform high altitude haze.

The principal features of Saturn's visible surface are stripes that parallel the equator, as shown on page 60. Six dark belts and three light zones have been seen continuously over 200 years of observations.

Spots have been observed in the upper atmosphere of Saturn. Unlike the Great Red Spot of Jupiter they are not permanent nor are they easily identifiable. The spots that have been observed have lifetimes up to a few months. Sometimes they are light, sometimes dark. They are confined to a region within 60 degrees of the equator and typically are a few thousand kilometers across. They may be comparable to hurricanes on Earth.

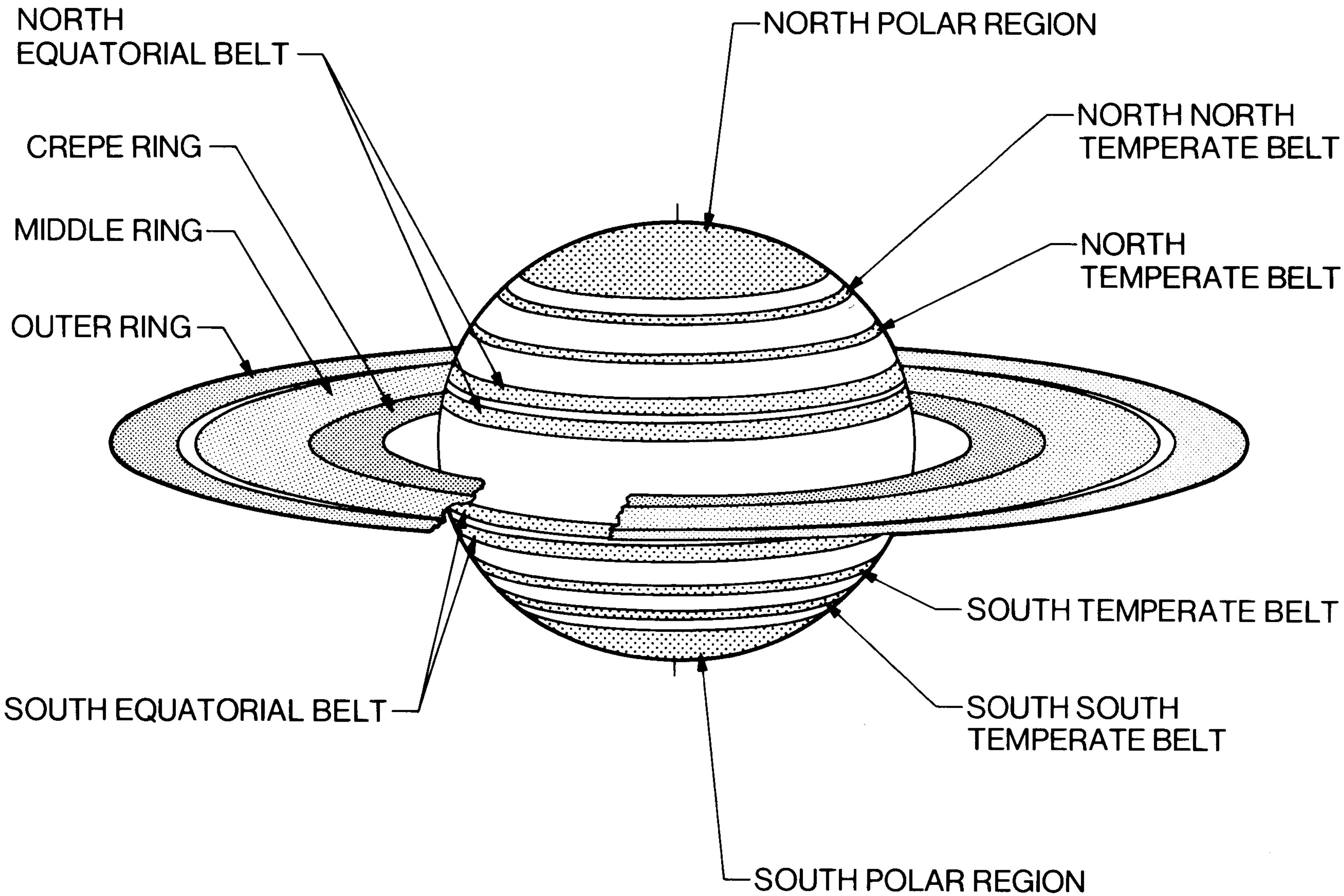
Saturn has 10 known satellites. The most recent discovery was Janus, found in 1966 by Audouin Dollfus. Janus has been seen in only a few photographs. It appears to travel in the plane of Saturn's rings and near them. Its low albedo and proximity to the rings make Janus difficult to observe except when the rings are edge-on to Earth and recent studies indicate that at least two separate satellites are masquerading under the name of Janus.

The largest known satellite in the solar system is Saturn's satellite Titan. Titan has a diameter of 5,800 km (3,600 mi.) and is known to have an atmosphere. In 1944, the late Dr. Gerard Kuiper detected a methane atmosphere on Titan. Titan's atmospheric pressure may be comparable to Earth's. Other molecules identified include ethane and probably acetylene and many scientists believe there is also a major undetected gas present. The most likely candidate is nitrogen. Some scientists believe organic compounds may be present on the surface of Titan, leading some to suggest it as a possible abode of some primitive life forms.

Iapetus is another Saturnian satellite that draws scientific interest. Its brightness varies by a factor of about five as it rotates on its axes, indicating that one face is bright and the other dark. The light face appears to be covered with ice but the composition of the dark face is unknown.

Saturn's rings have been a curiosity to astronomers since their discovery. Their origin is unknown but a number of hypotheses have been put forward. They might be the remains of some early satellite broken up by gravitation or remnants of the primordial material that somehow became trapped in orbit. The age of the rings is not known.

MAJOR FEATURES OF SATURN



The rings lie in Saturn's equatorial plane, which is tipped 27 degrees to the orbital plane of Saturn. Although it is certain the rings are not a solid sheet, little else is known about their composition and structure. Spectroscopy shows that they are made primarily of water ice or ice-covered silicates.

The individual particles probably vary from less than a millimeter to more than 10 meters, but most are a few centimeters in size -- about as big as a snowball.

Three distinct rings can be seen. The inner or "crepe" ring begins about 17,000 kilometers (10,000 miles) from the planet's visible cloud surface and extends for 15,000 km (10,000 mi.) to 32,000 km 20,000 mi.). The second ring begins at that point and extends for 26,000 km (16,000 mi.) to a distance of 58,000 km (36,000 mi.) from the planet. There, a phenomenon known as Cassini's Division breaks the rings' continuity. Cassini's Division is 2,600 km (1,600 mi.) wide.

The outer ring begins 60,000 km (38,000 mi.) from the equator of Saturn and appears to end 16,000 km (10,000 mi.) farther away at a distance of 76,000 km (48,000 mi.).

Cassini's Division is real. It is explained by a phenomenon in celestial mechanics. Any particle at that distance would have an orbital period of 11 hours, 17 1/2 minutes, just half the period of the satellite Mimas. The particle would be nearest Mimas at the same place in its orbit every second time around. This repeated gravitational perturbation would eventually move the particle to a different distance.

Accurate measurements of the ring thickness are not possible but limits have been placed. They appear to be somewhere between 1 and 4 km (0.6 to 2.5 mi.).

Until recently there was no evidence that Saturn has a magnetic field. Neither decimetric nor decametric radio emissions had been observed -- the kind of "radio noise" from Jupiter that was evidence for its magnetic field. But radiometric observations from the Earth-orbiting satellite IMP-6 have provided indirect evidence for a magnetic field. If a magnetic field is present, it is probably distorted by the rings. Direct measurement of any magnetic field and associated trapped radiation is one of the primary goals of the Voyager mission.

PLANETARY ATMOSPHERIC AND SURFACE DATA

Jupiter

Major atmospheric constituents are hydrogen and helium.

Minor constituents include methane, ammonia, acetylene, ethane and phosphoric acid. Hydrogen has been detected in the exosphere.

There is a thin layer of ammonia clouds with tops at about 106 degrees K (-269 degrees F) and about 0.2 atmospheres and base at about 150 degrees K (-189 degrees F) and about 0.6 atmospheres.

Pressure near the main cloud tops is about 1.5 atmospheres.

Main cloud top temperature is about 200 degrees K (-99 degrees F).

Beneath the clouds, temperatures and pressures rise rapidly.

It is not known whether Jupiter has a solid surface.

Saturn

Major atmospheric constituents are hydrogen and perhaps helium.

Minor constituents include methane and ammonia.

Temperature at tropopause is about 77 degrees K (-321 degrees F).

Pressure at tropopause is about 0.17 atmospheres.

It is not known whether Saturn has a solid surface.

Effective temperature is about 97 degrees K (-285 degrees F).

Beneath the clouds, temperatures and pressures rise rapidly.

Uranus

Major atmospheric constituents are hydrogen and perhaps helium.

Minor constituent is methane.

Effective temperature is 57 degrees K (-356 degrees F).

The atmosphere is very deep and higher temperature and high pressures certainly exist at depths.

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COMPARISON TABLE

PARAMETER	EARTH	JUPITER	SATURN
Radius (Equatorial)	6,378 km (3,963 mi.)	71,400 km (44,366 mi.)	60,000 km (37,300 mi.)
Satellites	1	13	10
Year	1	11.86	29.46
Day	23h 56m 04s	9h 55m 30s	10h 14m
Mass	1	317.9	95.2
Density (Water = 1)	5.5	1.3	0.7
Mean Distance From Sun	1 A.U.	5.2 A.U.	9.5 A.U.

-more-

THE SATELLITES OF JUPITER

NAME		DIAMETER (km- mi.)		SEMIMAJOR AXIS (km-mi.)		PERIOD (Days)
Amalthea	V	240	150	181,300	112,650	0.489
Io	I	3,640	2,660	421,600	261,950	1.769
Europa	II	3,050	1,895	670,900	416,400	3.551
Ganymede	III	5,270	3,275	1,070,000	664,900	7.155
Callisto	IV	5,000	3,105	1,880,000	1,168,000	16.689
Leda	XIII	2-14	1.3-8.5	11,110,000	6,903,500	240
Himalia	VI	170	110	11,470,000	7,127,000	250.6
Lysithea	X	6-32	3.7-20	11,710,000	7,276,000	260
Elara	VII	80	50	11,740,000	7,295,000	260.1
Ananke	XII	6-28	3.7-17	20,700,000	12,862,000	617
Carme	XI	8-40	5-25	22,350,000	13,176,000	692
Pasiphae	VIII	8-46	5-28.5	23,300,000	14,478,000	735
Sinope	IX	6-36	3.7-22	23,700,000	14,725,000	758

-more-

THE SATELLITES OF SATURN

NAME	DIAMETER (km-mi.)		SEMIMAJOR AXIS (km-mi.)		PERIOD (Days)
Janus	300 (est.)	187	168,700	105,000	0.815
Mimas	400	300	185,800	120,000	0.942
Enceladus	550	390	238,300	148,000	1.370
Tethys	1,200	745	294,900	183,200	1.888
Dione	1,150	715	377,900	235,000	2.737
Rhea	1,450	900	527,600	328,000	4.518
Titan	5,800	3,600	1,222,600	760,000	15.945
Hyperion	300 (est.)	187	1,484,100	922,000	21.276
Iapetus	1,800	1,120	3,562,900	2,214,000	79.33
Phoebe	200 (est.)	125	12,960,000	8,093,000	550.45

(Phoebe's motion is retrograde)

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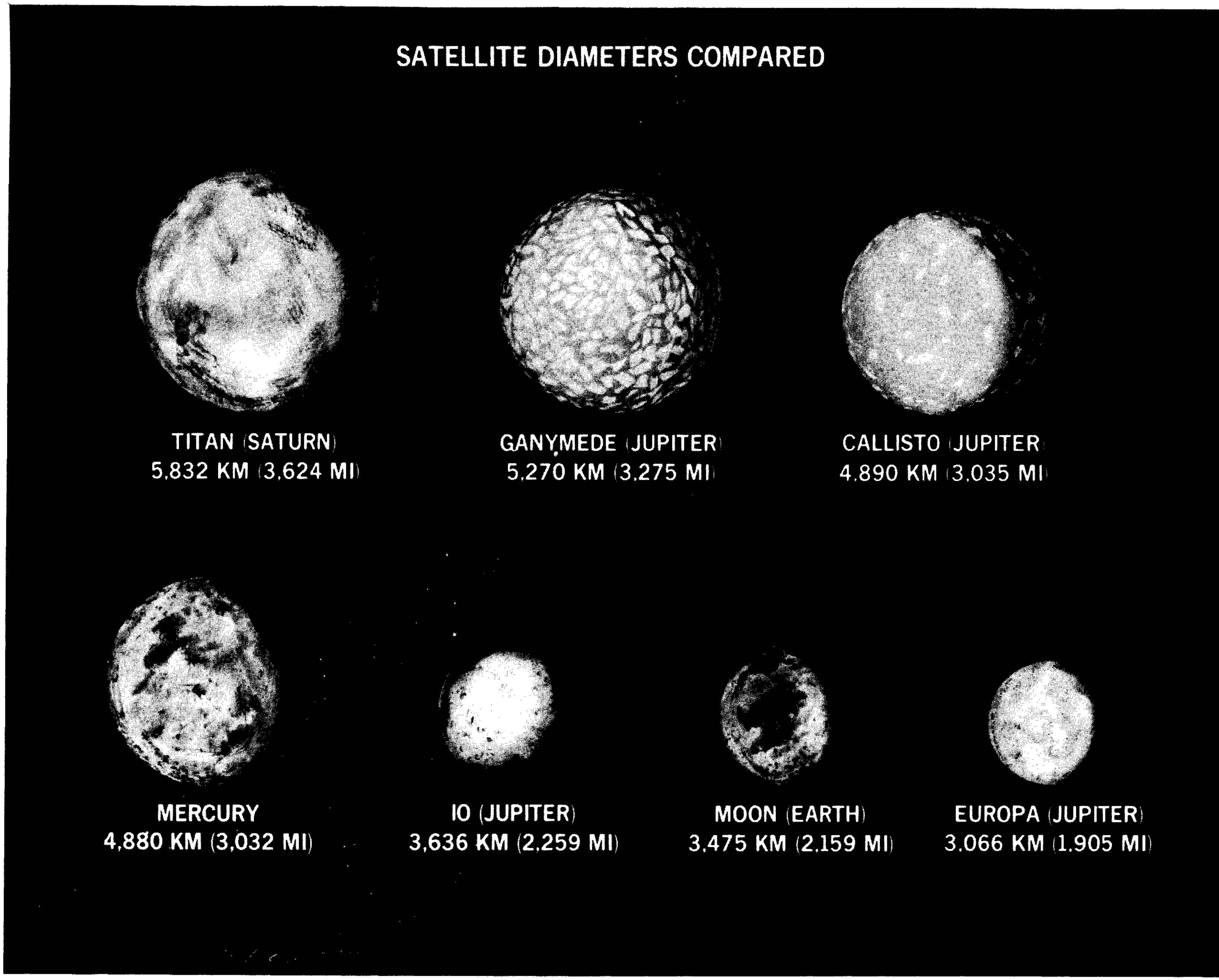

SATELLITE DIAMETERS COMPARED
TITAN (SATURN)
5,832 KM (3,624 MI)
GANYMEDE (JUPITER)
5,270 KM (3,275 MI)
CALLISTO (JUPITER)
4,890 KM (3,035 MI)
MERCURY
4,880 KM (3,032 MI)
IO (JUPITER)
3,636 KM (2,259 MI)
MOON (EARTH)
3,475 KM (2,159 MI)
EUROPA (JUPITER)
3,066 KM (1,905 MI)

VOYAGER SCIENCE

The Voyager mission to Jupiter and Saturn will address fundamental questions about the origin and nature of the solar system. Understanding interplanetary space and the other planets should give scientists a greater knowledge of Earth.

According to current theoretical models of the origin and evolution of the solar system, a gaseous nebula composed of solar material -- gases and dust of various elements -- collapsed to form the Sun. Some of the material remained behind and began to coalesce to form the planets, their satellites, the asteroids, comets and meteors. Temperature, pressure and density of the gas decreased with distance from the Sun. Formation of the planets is believed to have resulted from accretion of the nebular material. Observed differences in the planets are accounted for in these theories by variations in material and conditions at the places where they formed. Thus, knowledge gained at each planet can be related to others and should contribute to an overall understanding of the solar system as well as our own planet Earth.

Missions to Mars, Venus, Mercury and the Moon have contributed greatly to the body of knowledge. Each planet has its own personality, significantly different from others because of its unique composition and relationship to the Sun. Individual as they are, the inner planets are related as bodies that originated near the Sun and that are composed mainly of heavier elements. They are classified as "terrestrial planets," since the Earth is approximately representative.

Scientists have known for a long time that Jupiter, Saturn and the other outer planets differ significantly from terrestrial planets. They have low average densities; only hydrogen and helium among all the elements are light enough to match observations to date. Jupiter and Saturn are sufficiently massive (318 and 95 times Earth's mass, respectively) to insure that they have retained almost all their original material. They are, however, only relatively pristine examples of the material from which the solar system formed. While almost no material has been lost, the planets have evolved over their 4.6-billion-year lifetimes and the nature and ratio of the materials may have changed. If that 4.6-billion-year evolution can be traced, scientists will obtain a clearer picture of the early state of their region of the solar system.

- more -

Voyager Science Investigations

The scientific investigations of the Jupiter-Saturn mission are multipurpose taking data in a variety of environments. For example, the ultraviolet spectrometer studies planetary and satellite atmospheres and also interplanetary and interstellar hydrogen and helium. The magnetic fields experiment will examine the magnetospheres of the planets and also search for the transition between solar and galactic regions.

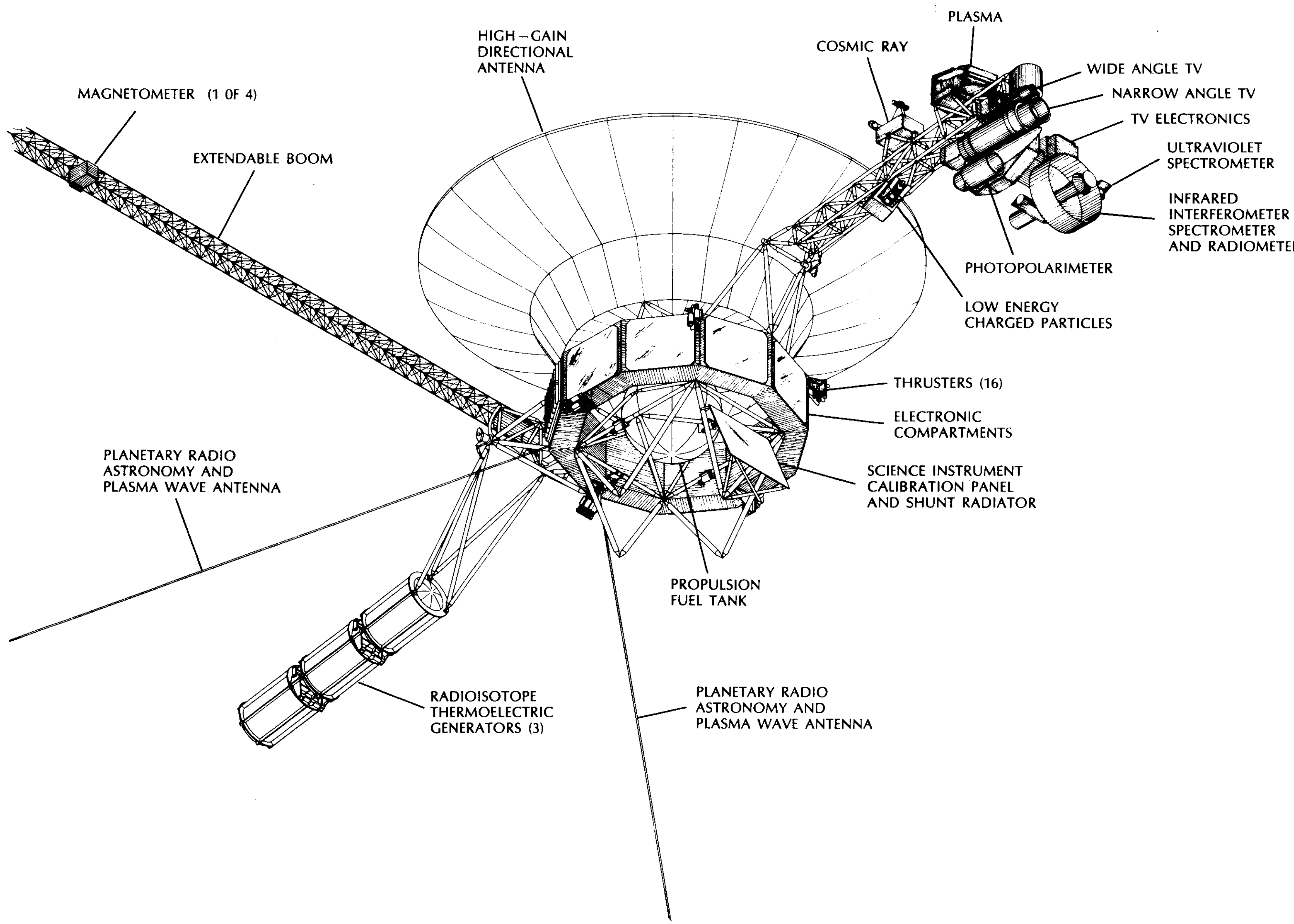
It is difficult to separate "planetary" from "interplanetary" instruments and investigations. There is, however, another grouping.

First, the optical scanners, mounted on the spacecraft's scan platform, have narrow fields of view and must be accurately pointed. They collect radiant energy (light, for example) from their targets and create images or spectral information that permit scientists to understand the physical form or chemical composition of the planets and satellites. Investigations in this group include the imaging science instruments (TV), infrared interferometer-spectrometer and radiometer, ultraviolet spectrometer and photopolarimeter.

The second family of investigations senses magnetic fields and fluxes of charged particles as the spacecraft passes through them. These instruments are fixed to the body of the spacecraft and have various fields of view. Their data taken together will give information on planetary magnetic fields (and indirectly, interior structure), on Sun-planet and planet-satellite interactions and on cosmic rays and the outer reaches of the solar plasma. These investigations are plasma, low energy charged particles, cosmic ray and magnetic fields.

A third family is planetary radio astronomy and plasma-wave investigations whose long antenna whips listen for planetary emissions, like those from Jupiter.

A radio investigation uses S-band and X-band links between spacecraft and Earth to gather information on planetary and satellite ionospheres and atmospheres and spacecraft tracking data to chart gravitational fields that affect Voyager's course.


PLASMA
COSMIC RAY
HIGH-GAIN DIRECTIONAL ANTENNA
WIDE ANGLE TV
NARROW ANGLE TV
TV ELECTRONICS
MAGNETOMETER (1 OF 4)
ULTRAVIOLET SPECTROMETER
EXTENDABLE BOOM
INFRARED INTERFEROMETER SPECTROMETER AND RADIOMETER
PHOTOPOLARIMETER
LOW ENERGY CHARGED PARTICLES
THRUSTERS (16)
ELECTRONIC COMPARTMENTS
PLANETARY RADIO ASTRONOMY AND PLASMA WAVE ANTENNA
SCIENCE INSTRUMENT CALIBRATION PANEL AND SHUNT RADIATOR
PROPULSION FUEL TANK
RADIOISOTOPE THERMOELECTRIC GENERATORS (3)
PLANETARY RADIO ASTRONOMY AND PLASMA WAVE ANTENNA

Cosmic-Ray Investigation

The cosmic-ray investigation has four principal scientific objectives:

- To measure the energy spectrum of electrons and cosmic-ray nuclei;
- To determine the elemental and isotopic composition of cosmic-ray nuclei;
- To make elemental and isotopic studies of Jupiter's radiation belts and to explore Saturn's environment, whose possible radiation belts have not yet been positively detected from Earth;
- To determine the intensity and directional characteristics of energetic particles as a function of radial distance from the Sun, and determine the location of the modulation boundary.

The cosmic ray investigation uses multiple-solid state detector telescopes to provide large solid-angle viewing. The low-energy telescope system covers the range from 0.5 to 9 million electron volts (MeV) per nucleon. The high-energy telescope system covers the range from 4 to 500 MeV. The electron telescope system covers the range from 7 MeV.

The cosmic-ray instrument weighs 7.5 kg (16.5 lb.) and uses 8.25 watts of power, including 2.8 watts for supplementary heaters.

Dr. Rochus E. Vogt of the California Institute of Technology is principal investigator.

Low-Energy Charged-Particle Investigation

Scientific objectives of the Low-Energy Charged Particle Investigation include studies of the charged particle composition, energy-distribution and angular distribution with respect to:

- Saturn's magnetosphere (exploratory) and Jupiter's magnetosphere (detailed studies);

- Interactions of charged particles with the satellites of Jupiter and Saturn and possibly with the rings of Saturn;
- Measurements of quasi-steady interplanetary flux and high-energy components of the solar wind;
- Determination of the origin and interstellar propagation of galactic cosmic rays (those that come from outside the solar system);
- Measurements of the propagation of solar particles in the outer solar system.

The investigation uses two solid state detector systems on a rotating platform mounted on the scan platform boom. One system is a low energy magnetospheric particle analyzer with large dynamic range to measure electrons with energy ranging from 15,000 electron volts (15 KeV) to greater than 1 MeV; and ions in the energy range from 15,000KeV per nucleon to 160 MeV per nucleon.

The second detector system is a low-energy particle telescope that covers the range from 0.15 MeV per nucleon to greater than about 10 MeV per nucleon.

The Low-Energy Charged-Particle Investigation weighs 7.5 kg (16.5 lb.) and draws 9.46 watts including 4.66 watts for supplementary heaters.

Dr. S. M. (Tom) Krimigis of the Applied Physics Laboratory, Johns Hopkins University, is principal investigator.

Magnetic Fields Investigation

The magnetic field of a plane is an externally measurable manifestation of conditions deep in its interior.

The magnetic fields instruments on Voyager 1 and 2 will determine the magnetic field and magnetospheric structure at Jupiter and Saturn; they will study the interaction of the magnetic field and the satellites that orbit the planets inside that field and will study the interplanetary-interstellar magnetic field.

Four magnetometers are carried aboard Voyager. Two are low-field, three-axis instruments located on a boom to place them as far from the spacecraft body as possible. This allows separation of the spacecraft's magnetic field from the external field that is to be measured. The other two magnetometers are high field, three-axis instruments mounted on the spacecraft body.

The boom-mounted, low-field instruments will measure the magnetic fields in the range from 10p tesla (0.010 gamma) to 50u tesla (50,000 gamma). (Fifty-thousand gamma equals one-half gauss, about the average magnetic field strength at the surface of Earth.)

The high-field instruments cover the range from 25n tesla (25 gamma) to 2m tesla (20 gauss). While the highest field strengths measured by the Pioneer spacecraft at Jupiter were about 1.4m tesla (14 gauss) scientists expect that localized, stronger fields may be associated with the planets or some of their satellites.

Total weight of the magnetic fields investigation is 5.6 kg (12.3 lb.). The instruments use 2.1 watts of power.

Dr. Norman Ness of NASA's Goddard Space Flight Center is principal investigator.

Infrared Spectroscopy and Radiometry Investigation

The IRIS instrument is designed to perform spectral and radiometric measurements of the Jovian and Saturnian planetary systems and targets of opportunity during the cruise phase of the mission.

Scientific objectives for IRIS are:

- Measurement of the energy balance of Jupiter and Saturn.
- Studies of the atmospheric compositions of Jupiter, Saturn, Titan and other satellites.
- Temperature structure and dynamics of the atmospheres.
- Measurements of composition and characteristics of clouds and aerosols.

- Studies of the composition and characteristics of ring particles (at Saturn) and the surfaces of those satellites the instrument will observe.

The instrument provides broad spectral coverage, high spectral resolution and low noise equivalence radiance through use of Michelson interferometers. These characteristics of the instrument, as well as the precision of the radiometer, will allow scientists to acquire information about a wide variety of scientific questions concerning the atmospheres of the planets and satellites, local and global energy balance and the nature of satellite surfaces and the rings of Saturn.

Two versions of the IRIS instrument are being prepared for possible use on the spacecraft. The first, known simply as IRIS, was designed for use at the Jupiter and Saturn planetary systems. It is an improved version of the IRIS instrument which flew to Mars on Mariner 9 in 1971-72. The second, known as the Modified IRIS, or MIRIS, was designed later to be able to perform farther out in the solar system at Uranus. Either instrument can be flown on the spacecraft because the principal mechanical and electrical interfaces are identical. In general, the MIRIS instruments will be flown on both Voyager spacecrafts if they are completed in time because they offer advantages at Jupiter and Saturn as well as at Uranus. The accompanying table compares the characteristics of the two instrument versions.

IRIS Instruments
Comparison of Characteristics

	IRIS	MIRIS
Michelson Interferometer Spectral range	2.5-50 μM	1.4-10, 15-200 μM
Radiometer Spectral Range	0.3-2.0 μM	0.3-1.2 μM
Noise Equivalent Radiance (Wcm^{-2} SR^{-1}/cm^{-1})	7×10^{-10}	7.5×10^{-12}
System Operating Temperature	200°K	140°K
Field-of-view	0.25°	0.15°
Weight	18.6 kg	30.2 kg
Power, watts	20.1	14.0

- more -

Dr. Rudolf A. Hanel of Goddard Space Flight Center is principal investigator.

Photopolarimetry Investigation

A great deal of information about the composition of an object can be learned from the way that object reflects light. The Voyager spacecraft's photopolarimeter will observe how light reflected from Jupiter, Saturn and their satellites is polarized by the chemicals and aerosols in the atmospheres and on the surfaces.

The photopolarimeter will measure methane, molecular hydrogen and ammonia above the cloud tops. It will study aerosol particles in the atmospheres of the planets and satellites; the textures and compositions of the surfaces of satellites; size, albedo, spatial distribution, shape and orientation of particles in Saturn's rings; measure optical and geometric thickness of the rings; and observe the sky background to search for interplanetary and interstellar particles.

The instrument is made up of a 15-cm (60 in.) Cassegrain telescope, aperture sector, polarization analyzer wheel, filter wheel and a photomultiplier tube detector. The filter wheel carries eight filters ranging from 2,350-Angstrom to 7,500-Angstrom wavelength; three linear polarizers (0 degrees, 60 degrees and 120 degrees) plus "open" or blank. The instrument's field of view can be set at 3.5 degrees, 1 degree, 1/4 degree and 1/16 degree.

The photopolarimeter weighs 4.4 kg (9.7 lb.) and uses 2.6 watts average power.

Dr. Charles F. Lillie of the University of Colorado's Laboratory for Atmospheric and Space Physics is principal investigator.

Planetary Radio Astronomy Investigation

The Planetary Radio Astronomy investigation consists of a stepped frequency radio receiver that covers the range from 20 kHz to 40.5 mHz and two monopole antennas 10 m (33 ft.) long, to detect and study a variety of radio signals emitted by Jupiter and Saturn.

Scientific objectives of the investigation include detection and study of radio emissions from Jupiter and Saturn and their sources and relationship to the satellites, the planets' magnetic fields, atmospheric lightning and plasma resonances. The instrument will also measure planetary and solar radio bursts from new directions in space and will relate them to measurements made from Earth.

Jupiter emits enormous bursts of radio energy that are not clearly understood. They appear to be related to the planet's magnetosphere, its rotation and even to passage of the satellite Io. The energy released in the strongest bursts is equivalent to that of multi-megaton hydrogen bombs.

The receiver is designed to provide coverage in two frequency bands -- one covering the range from 20.4 kHz to 1,345 kHz, the second from 1,228.8 kHz to 40.5 mHz. The receiver bandwidth is 1 kHz in the low-frequench range and 200 kHz in the high- frequency band. There are three signal input attenuators to provide switchable total attenuation from 0 to 90 decibels.

The instrument weighs 7.7 kg (17 lbs.) and draws 6.7 watts of power.

Principal investigator is Dr. James W. Warwick of the Department of Astro-Geophysics, University of Colorado.

Plasma Investigation

Plasma, clouds of ionized gases, moves through the interplanetary region and comes from the Sun and from stars. The plasma investigation uses two Faraday-cup plasma detectors, one pointed along the Earth-spacecraft line, the other at right angles to that line.

Scientific objectives of the plasma investigation are:

- Determine properties of the solar wind, including changes in the properties with increasing distance from the Sun;

- Study of the magnetospheres that are intrinsic to the planets themselves and that corotate with the planets independent of solar wind activity;

- Study of the satellites of Jupiter and Saturn and the plasma environment of Io;

- Detection and measurement of interstellar ions.

The Earth-pointing detector uses a novel geometrical arrangement that makes it equivalent to three Faraday cups and determines macroscopic properties of the plasma ions. With this detector, accurate values of the velocity, density and pressure can be determined for plasma from the Earth (1 A.U.) to beyond Saturn (10 A.U.). Two sequential energy scans are employed to allow the instrument to cover a broad range of energies -- from 10 electron volts (eV) to 6,000 electron volts (6 KeV). Significant measurements can be made between subsonic and supersonic speeds in cold solar wind or hot planetary magnetosheath.

The variable energy resolution allows scientists to detect and sort out ions that flow with the solar wind at the same time they are measuring the solar wind's properties.

The instrument has a large (180-degree) field of view at planetary encounters and a 90-degree field of view in the solar wind. No electrical or mechanical scanning is necessary.

The other Faraday cup, a side-looking or lateral detector, measures electrons in the range of 10 eV to 6 KeV and should improve spatial coverage for any drifting or corotating positive ions during planetary encounters.

The instrument was designed primarily for exploring planets' magnetospheres. It is capable of detecting hot subsonic plasma such as has been observed in the Earth's magnetosphere and is expected from ions originating in the McDonough-Brice ring of Io. The instrument's large angular acceptance allows detection of plasma flows well away from the direction of the Sun, such as plasma flows that corotate with the planet.

The plasma instrument weighs 9.9 kg [illegible].8 lb.) and draws 9.9 watts of power.

Dr. Herbert Bridge of the Massachusetts Institute of Technology is principal investigator.

- more -

Plasma Wave Investigation

Scientific objectives of the plasma wave investigation are measurements of thermal plasma density profiles at Jupiter and Saturn, studies of wave-particle interactions and study of the interactions of the Jovian and Saturnian satellites with their planets' magnetospheres.

The plasma wave instrument will measure electric-field components of local plasma waves over the frequency range from 10 Hz to 56 kHz.

The instrument shares the two extendable 10-m (33 ft.) electric antennas provided by the planetary radio astronomy experiment team. The two groups use the antennas in different ways. The plasma wave investigation uses the antennas to form a Vee-type balanced electric dipole, while the radio astronomy investigation uses them as a pair of orthogonal monopoles.

In the normal format, the plasma wave signals are processed with a simple 16-channel spectrum analyzer. At planetary encounters, the system will provide a spectral scan every four seconds.

The plasma wave system has a broadband amplifier that will use the Voyager video telemetry link to give electric field waveforms, with a frequency range from 50 Hz to 10 kHz, at selected times during planet encounters.

The investigation is designed to provide key information on the wave-particle interaction phenomena that control important aspects of the dynamics of the magnetospheres of Jupiter and Saturn. Wave-particle interactions play extremely important roles at Earth and scientists understand that at least the inner magnetosphere of Jupiter is conceptually similar to that of Earth despite the vast difference in size and in energy of the trapped particles.

In addition, the satellites of Jupiter and Saturn appear to provide important localized sources of plasma and field-aligned currents and they should significantly affect the trapped-particle populations.

The instrument weighs 1.4 kg (3.1 lb.) and draws 1.6 watts of power.

Dr. Frederick L. Scarf of TRW Defense and Space Systems is principal investigator.

Radio Science Investigation

The spacecraft's communications system will be used to conduct several investigations by observing how the radio signals are changed on their way to Earth.

By measuring the way signals die out and return when the spacecraft disappears behind a planet or satellite and then reappears, the radio science team can determine the properties of planetary and satellite atmospheres and ionospheres.

The radio signals also allow scientists to make precise measurements of the spacecraft's trajectory as it passes near a planet or satellite. Post-flight analyses allow determination of the mass of a body and its density and shape.

The rings of Saturn will also be explored by the radio science team by measuring the scattering of the radio signals as they travel through the rings. This will provide measurements of ring mass, particle size distribution and ring structure.

The investigation uses the microwave receivers and transmitters on the spacecraft as well as special equipment at the Deep Space Network tracking stations. The spacecraft transmitters are capable of sending 9.4, 20 or 28.3 watts at S-band, and 12 or 21.3 watts at X-band. The spacecraft antenna is a 3.67 m (12 ft.) parabola and is aimed by special maneuvers performed during planet occultations.

Dr. Von R. Eshleman of the Center for Radar Astronomy, Stanford University, is the Leader of the Radio Science Team.

Imaging Science Investigation

The Voyager imaging system is based on those flown aboard Mariner spacecraft, with advancements and changes dictated by the specific requirements of flybys of Jupiter, Saturn and their satellites.

Science objectives for the imaging science investigation include reconnaissance of the Jupiter and Saturn systems, including high-resolution photography of atmospheric motions, colors and unusual features (such as the Great Red Spot and similar smaller "spots"), vertical structure of the atmospheres of the planets, comparative and detailed geology of satellites, satellite size and rotation and detailed studies of the rings of Saturn.

Two television-type cameras are mounted on the spacecraft's scan platform: a 200mm focal-length, wide-angle camera with 4,000-Angstrom to 6,200-Angstrom sensitivity and a 1,500mm focal-length, narrow-angle camera with a 3,200-Angstrom to 6,200-Angstrom range.

The discs of Jupiter and Saturn will exceed the field of view of the narrow-angle camera about 20 days before closest approach. At that time, resolution will be about 400 km (250 mi.). For several days before and after closest approach, scientists will have several simultaneous imaging opportunities:

- Photography at high resolution of planets whose angular diameters are many times larger than the field of view;
- Close encounters (some comparable with Mariner 10's Mercury flybys) with the major satellites. For example, all four Galilean satellites (Jupiter's largest) will probably be photographed at resolution better than 4 km (2.5 mi.);
- More distant photography of several additional satellites;
- High-resolution photography of Saturn's rings.

To exploit such a variety of opportunities, it is necessary for the spacecraft to return large quantities of imaging data. The camera-spacecraft system has been designed to return imaging data over a wide range of telemetry rates in real time. Data can also be recorded on board the spacecraft for later playback to Earth -- during occultation by Jupiter, for instance.

Each camera is equipped with a filter wheel whose eight individual filters have a variety of uses:

The wide-angle camera's filter wheel contains one clear filter, one each in violet, blue, green and orange wavelengths, a seven-Angstrom sodium-D filter for special observations near Io and other satellites and two 100-Angstrom filters at the wavelength of methane absorption for study of the distribution of methane in the atmospheres of Jupiter, Saturn, Titan and Uranus.

The narrow angle camera's filter wheel carries two clear filters, two green and one each of violet, blue, orange and ultraviolet.

Voyager will be the first imaging system with narrow-band capability to directly observe distribution of atomic and molecular species. The seven-Angstrom sodium-D filter is the narrowest bandwidth filter ever flown with this kind of camera.

Because the Voyager spacecraft will pass the planets and satellites at high velocities and must take pictures in dimmer light than Mariner missions to the inner planets, image smear conditions are more severe than on previous flights. To overcome these problems, the camera's preamplifiers have been redesigned to lower system noise and and to incorporate a high gain state. Both changes are meant to provide high quality images with minimum smear.

During the several months before closest approach, the narrow-angle cameras will photograph Jupiter and Saturn regularly and often to provide information on cloud motions. These pictures will be taken on a schedule which would permit scientists to make motion pictures in which the planet's rotation has been "frozen" so that only the cloud motions are apparent. Resolution during the period will range from about 1,600 km (1,000 mi.) to about 400 km (250 mi.). Once the planet grows larger than the narrow angle camera's field of view, the wide-angle camera will begin its work. The narrow-angle camera will then repeatedly photograph portions of the planets that warrant special scientific interest. Both cameras will be shuttered simultaneously during these periods so scientists can relate small scale motions to larger patterns.

Because of the nature of the planetary flybys the cameras will not be able to concentrate on a single target for hours at a time. As each satellite moves it will present an everchanging appearance to the cameras. The planets' clouds will also be in constant motion. Therefore, observational sequences are structured to provide repeated images at differing intervals for each target. Additionally, large amounts of multicolor imaging data will be obtained for the planets and satellites.

The camera system weighs 38.2 kg (84 lb.) and uses 41.7 watts of power including 8.6 watts for instrument and scan platform supplementary heaters.

Dr. Bradford A. Smith of the University of Arizona is the leader of the Imaging Science Team.

Ultraviolet Spectroscopy Investigation

The ultraviolet spectrometer looks at the planets' atmospheres and at interplanetary space.

Scientific objectives of the investigation are:

- To determine distributions of the major constituents of the upper atmospheres of Jupiter, Saturn and Titan as a function of altitude;
- To measure absorption of the Sun's ultraviolet radiation by the upper atmospheres as the Sun is occulted by Jupiter, Saturn and Titan;
- To measure ultraviolet airglow emissions of the atmospheres from the bright discs of the three bodies, their bright limbs, terminators and dark sides;
- Determine distribution and ratio of hydrogen and helium in interplanetary and interstellar space.

The instrument measures ultraviolet radiation in 1,200-Angstrom bandwidth in the range from 400 to 1,800 Angstroms. It uses a grating spectrometer with a microchannel plate electron multiplier and a 128-channel anode array. A fixed position mirror reflects sunlight into the instrument during occultation. The instrument has a 0.86-degree by 0.6-degree field of view during occultation and a 0.86- by 2-degree field of view for airglow measurements.

The ultraviolet spectrometer weighs 4.5 kg (9.9 lb.) and uses 2.5 watts of power.

Dr. A. Lyle Broadfoot of Kitt Peak National Observatory is principal investigator.

INVESTIGATION	PRINCIPAL INVESTIGATOR	INSTRUMENTS AND FUNCTIONS
Imaging Science	Team Leader, Dr. Bradford Smith, University of Arizona	Two TV cameras with 1500mm, f/8.5 and 200mm, f/3 optics, multiple filters, variable shutter speeds and scan rates. Wide-angle field of view, 56x55 millirad (about 3 deg. square). On scan platform.
Infrared Spectroscopy and Radiometry	Dr. Rudolf Hanel, Goddard Space Flight Center	Spectrometer-radiometer measuring temperatures and molecular gas compositions, with narrow 1/4-deg field of view producing measurements every 48 sec. on scan platform.
Ultraviolet Spectroscopy	Dr. A. Lyle Broadfoot, Kitt Peak National Observatory	Grating spectrometer measuring ion, atomic, and small-molecular gas abundances, spectral range 400-1600 Angstroms, on scan platform.
Photopolarimetry	Dr. Charles Lillie, University of Colorado	200mm telescope with variable apertures, filters, polarization analyzers and PMT detector, on scan platform.
Plasma	Dr. Herbert Bridge, Massachusetts Institute of Technology	Dual plasma detectors, one aligned toward Earth-Sun and one perpendicular, with detection ranges from 10eV to 6 keV.

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INVESTIGATION	PRINCIPAL INVESTIGATOR	INSTRUMENTS AND FUNCTIONS
Low-Energy Charged-Particle	Dr. S. M. Krimigis, Johns Hopkins, Applied Physics Laboratory	Dual rotating solid-state detector sets, covering various ranges from 10 keV to more than 30 MeV/nucleon.
Cosmic Ray	Dr. R. E. Vogt, California Institute of Technology	High-energy, low-energy, and electron telescope systems using arrays of solid-state detectors, several ranges from 0.15 to 500 MeV/nucleon.
Magnetic Fields	Dr. Norman Ness, Goddard Space Flight Center	Two low-field triaxial flux-gate magnetometers located roughly 10 m (33 ft.) from spacecraft on boom, two high-field (20 gauss) instruments mounted on spacecraft.
Planetary Radio Astronomy	Dr. James Warwick, University of Colorado	Two 10-m (33 ft.) whip antennas and two-band receiver (20.4-1300 kHz, 2.3-40.5 mHz), detecting planetary radio emissions and bursts and solar stellar bursts.
Plasma Wave	Dr. Frederick L. Scarf TRW Space and Defense Systems	Uses 10-m (33 ft.) planetary radio astronomy antennas with step-frequency detector and waveform analyzer to measure plasma waves, thermal plasma density profiles at Jupiter and Saturn, satellite/magnetosphere interactions, wave particle interactions.

- more -

INVESTIGATION	PRINCIPAL INVESTIGATOR	INSTRUMENTS AND FUNCTIONS
Radio Science	Team Ieader, Dr. Von R. Eshleman, Stanford University	Uses spacecraft S-band/X-band links in planet, satellite and Saturn ring occultations to perceive changes in refractivity and absorption. Celestial mechanics information calculated from tracking data.

VOYAGER SCIENCE TEAMS

IMAGING SCIENCE

Bradford A. Smith	Team Leader University of Arizona
Geoffrey A. Briggs	Jet Propulsion Laboratory
A. F. Cook	Smithsonian Institution
G. E. Danielson Jr.	Jet Propulsion Laboratory
Merton Davies	Rand Corporation
G. E. Hunt	Meteorological Office United Kingdom
Tobias Owen	State University of New York
Carl Sagan	Cornell University
Lawrence Soderblom	U.S. Geological Survey
V. E. Suomi	University of Wisconsin
Harold Masursky	U.S. Geological Survey

RADIO SCIENCE

Von R. Eshelman	Team Leader Stanford University
J. D. Anderson	Jet Propulsion Laboratory
T. A. Croft	Stanford Research Institute
Gunnar Fjeldbo	Jet Propulsion Laboratory
G. S. Levy	Jet Propulsion Laboratory
G. L. Tyler	Stanford University
G. E. Wood	Jet Propulsion Laboratory

VOYAGER SCIENCE TEAMS (Continued)

PLASMA WAVE

Frederick L. Scarf	Principal Investigator TRW Systems
D. A. Gurnett	University of Iowa

INFRARED SPECTROSCOPY & RADIOMETRY

Rudolf A. Hanel	Principal Investigator Goddard Space Flight Center
B. J. Conrath	Goddard Space Flight Center
P. Gierasch	Cornell University
V. Kunde	Goddard Space Flight Center
P. D. Lowman	Goddard Space Flight Center
W. Maguire	Goddard Space Flight Center
J. Pearl	Goddard Space Flight Center
J. Pirraglia	Goddard Space Flight Center
R. Samuelson	Goddard Space Flight Center
Cyril Ponnamperuma	University of Maryland
D. Gautier	Meudon, France

ULTRAVIOLET SPECTROSCOPY

A. Lyle Broadfoot	Principal Investigator Kitt Peak National Observatory
J. L. Bertaux	Service d'Seronomie du Centre National de la Recherche Scientifique (CNRS), France
J. Blamont	Service d'Aeronomie du CNRS
T. M. Donahue	University of Michigan
R. M. Goody	Harvard University

VOYAGER SCIENCE TEAMS (Continued)

ULTRAVIOLET SPECTROSCOPY (Cont'd.)

A. Dalgarno	Harvard College Observatory
Michael B. McElroy	Harvard University
J. C. McConnell	York University, Canada
H. W. Moos	Johns Hopkins University
M. J. S. Belton	Kitt Peak National Observatory
D. F. Strobel	Naval Research Laboratory

PHOTOPOLARIMETRY

Charles F. Lillie	Principal Investigator University of Colorado
Charles W. Hord	University of Colorado
D. L. Coffeen	Goddard Institute for Space Studies, New York City
J. E. Hansen	Goddard Institute for Space Studies
K. Pang	Science Applications Inc.

PLANETARY RADIO ASTRONOMY

James W. Warwick	Principal Investigator University of Colorado
J. K. Alexander	Goddard Space Flight Center
A. Boischot	Observatoire de Paris, France
W. E. Brown	Jet Propulsion Laboratory
T. D. Carr	University of Florida
Samuel Gulkis	Jet Propulsion Laboratory
F. T. Haddock	University of Michigan
C. C. Harvey	Observatoire de Paris, France

VOYAGER SCIENCE TEAMS (Continued)

PLANETARY RADIO ASTRONOMY (Cont'd.)

Y. LeBlanc	Observatoire de Paris, France
R. G. Peltzer	University of Colorado
R. J. Phillips	Jet Propulsulsion Laboratory
D. H. Staelin	Massachusetts Institute of Technology

MAGNETIC FIELDS

Norman F. Ness	Principal Investigator Goddard Space Flight Center
Mario H. Acuna	Goddard Space Flight Center
K. W. Behannon	Goddard Space Flight Center
L. F. Burlaga	Goddard Space Flight Center
R. P. Lepping	Goddard Space Flight Center
F. M. Neubauer	Technische Universitat West Germany

PLASMA SCIENCE

Herbert S. Bridge	Principal Investigator Massachusetts Institute of Technology
J. W. Belcher	Massachusetts Institute of Technology
J. H. Binsack	Massachusetts Institute of Technology
A. J. Lazarus	Massachusetts Institute of Technology
S. Olbert	Massachusetts Institute of Technology
V. M. Vasyliunas	Max Planck Institute, West Germany

VOYAGER SCIENCE TEAMS (Continued)

PLASMA SCIENCE (Cont'd.)

L. F. Burlaga	Goddard Space Flight Center
R. E. Hartle	Goddard Space Flight Center
K. W. Ogilvie	Goddard Space Flight Center
G. L. Siscoe	University of California Los Angeles
A. J. Hundhausen	High Altitude Observatory

LOW-ENERGY CHARGED PARTICLES

S. M. Krimigis	Principal Investigator Johns Hopkins University
T. P. Armstrong	University of Kansas
W. I. Axford	Max Planck Institute
C. O. Bostrom	Johns Hopkins University
C. Y. Fan	University of Arizona
G. Gloeckler	University of Maryland
L. J. Lanzerotti	Bell Telephone Laboratories

COSMIC RAY

R. E. Vogt	Principal Investigator California Institute of Technology
J. R. Jokipii	University of Arizona
E. C. Stone	California Institute of Technology
F. B. McDonald	Goddard Space Flight Center
B. J. Teegarden	Goddard Space Flight Center
James H. Trainor	Goddard Space Flight Center
W. R. Webber	University of New Hampshire

VOYAGER MISSION HIGHLIGHTS

VOYAGER 2			Date	VOYAGER 1		
EVENT	Approximate Range			EVENT	Approximate Range	
	kilometers	miles			kilometers	miles
Launch			Aug. 20, 1977			
Near Earth Science Seq.			Aug. 20-29, 1977			
TCM-1*			Aug. 25-Sept. 4, 1977			
			Sept. 1, 1977	Launch		
			Sept. 1-16, 1977	Near Earth Science Seq.		
			Sept. 6-16, 1977	TCM-1*		
			Dec. 15, 1978	Start Jupiter Imaging	80,000,000	50,000,000
			Mar. 4, 1979	Amalthea	415,000	273,000
			Mar. 5, 1979	Jupiter Closest Approach	278,000	173,000
			Mar. 5, 1979	Io	22,000	13,700
			Mar. 5, 1979	Europa	733,000	455,000
			Mar. 5, 1979	Ganymede	115,000	71,500
			Mar. 6, 1979	Callisto	124,000	77,000
			April --1979	Conclude Jupiter Imaging		
Start Jupiter Imaging	75,000,000	47,000,000	Apr. 20, 1979			
Callisto	220,000	137,000	July 8, 1979			
Ganymede	55,000	34,000	July 9, 1979			
Europa	201,000	125,000	July 9, 1979			
Amalthea	550,000	341,000	July 9, 1979			
Jupiter Closest Approach	643,000	400,000	July 10, 1979			
Conclude Jupiter Imaging			August --1979			
			August --1980	Start Saturn Imaging	100,000,000	62,000,000
			Nov. 11, 1980	Titan	4,000	2,550
			Nov. 12, 1980	Saturn Closest Approach**	138,000	85,800
			January --1981	Conclude Saturn Imaging		
Start Saturn Imaging	100,000,000	62,000,000	June, 1981			
Saturn Closest Approach***	102,000	63,400	Aug. 27, 1981			
Saturn Rings Edge	38,000	23,600	Aug. 27, 1981			
Conclude Saturn Imaging			October --1981			
Uranus Encounter			January --1986			

*Trajectory Correction Maneuver-1 may be conducted in two or three parts at about 24-hour intervals because of thermal constraints at this spacecraft-sun distance. Each spacecraft will execute at least seven additional TCMS prior to Saturn encounter.

**Also encounter imaging of satellites Tethys, Enceladus, and Rhea.

***Also encounter imaging of satellites Titan, Rhea, Tethys and Enceladus.

-more-

VOYAGER LAUNCH PREPARATIONS

The Voyagers will be launched aboard Titan Centaurs 6 and 7 from Complex 41 of the Titan III Complex at the Air Force's Eastern Test Range. Launch will be under the direction of John F. Kennedy Space Center's (KSC's) Expendable Vehicles Directorate, Kennedy Space Center, Fla.

The Voyager launch opportunity extends from August 20 to September 23, imposing stringent scheduling requirements on the team to conduct both launches from a single pad within a short time span. The schedule is even more demanding because of the plan to launch the Voyager space vehicles 11 days apart to improve the probability of getting both missions underway before the end of the window September 23.

The Titan III facility has two active pads, LC-40 and LC-41, but only Complex 41 has been modified to accommodate NASA's hydrogen-fueled Centaur.

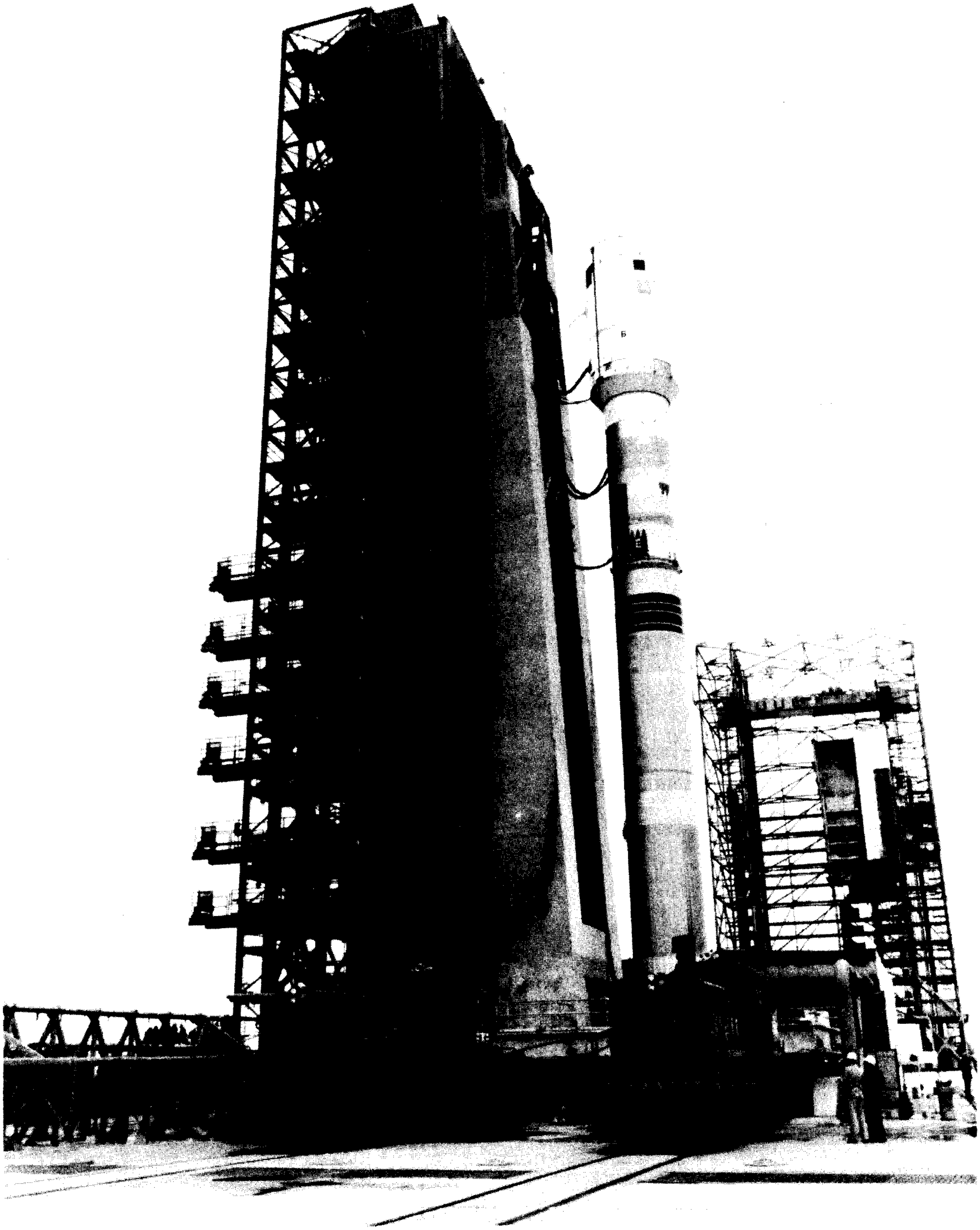
The dual Titan Centaur launch operation is almost a replay of the back-to-back Viking launches conducted from Complex 41 in the late summer of 1975. The Voyager launches are the last missions now scheduled for the Titan Centaur rocket.

Launch Facilities

The Titan III Complex--built on manmade islands in the Banana River--consists of: Solid rocket motor servicing and storage areas; a Vertical Integration Building (VIB); a Solid Motor Assembly Building (SMAB); Launch Complexes 40 and 41; and a double-track locomotive system which transports the mated Titan core and Centaur vehicle from the VIB through through SMAB to launch Complex 41. The rail system covers a distance of about 32 km (20 mi.) to link the various facilities of the complex.

Hardware Assembly

The Titan, Centaur and Centaur portion of the shroud are erected and mated in the VIB on a mobile transporter--umbilical mast structure. Attached to the transporter are three vans which remain connected to the transporter and



vehicle throughout the receipt-to-launch sequence. Upon completion of integrated tests in the VIB, the assembled Titan and Centaur are moved on the transporter to the SMAB. After the solid rocket motors and core stages are structurally mated, the vehicle is moved to the launch complex. A mobile service structure provides access to all mated vehicle stages, and an environmental enclosure ("white room") protects the Centaur and the spacecraft.

Because of the quick turnaround launch sequence required by Voyager, the Titan Centaur for the second mission (TC-6) was processed first. The Titan core for TC-6 was erected in the VIB on October 12, 1976, and the Centaur stage was mated with it October 19. TC-6, without its solid rocket boosters, was moved to Complex 41 for checkout and major tests January 4, 1977. It was moved back into the VIB for storage April 6.

The Titan core for TC-7 was erected on February 3 and the Centaur stage mated with it February 16. TC-7 was moved into the SMAB for the installation of its solid rocket boosters during the first week of April and to Complex 41 April 14.

TC-7 will remain at Complex 41 for testing and final launch preparations through launch of the first Voyager mission, now scheduled for August 20.

TC-6 will remain in storage in the VIB until July 20 when it is to be moved into the SMAB for mating with its solid rocket boosters. The move to Complex 41 for final preparations for launch of the second Voyager mission is scheduled for one day after the launch of TC-7 with the first Voyager.

Spacecraft Preparations

Elements of the Voyager spacecraft began arriving at Kennedy Space Center in April for pre-launch operations, including assembly, checkout, fueling and encapsulation in the payload section of the shroud. Spacecraft processing is the responsibility of the Jet Propulsion Laboratory, Pasadena, Calif. The propulsion modules were processed in ESA-60A and the mission modules were processed in Hangar AO, both at Cape Canaveral Air Force Station. Final assembly and encapsulation was accomplished in Spacecraft Assembly and Encapsulation Facility (SAEF) 1 and 2 in the KSC Industrial Area.

The "pathfinder" or proof test model spacecraft was received at Kennedy Space Center April 11 and passed through the processing cycle to be followed by the flight spacecraft. It was erected atop TC-7 at Complex 41 during the third week of May for pad operations and countdown tests.

The first flight spacecraft was received at Kennedy Space Center April 25. After initial processing of the propulsion and mission modules at the Cape they were moved to SAEF-1 for mating in mid-July.

The nuclear electrical generator power source will be installed July 31 prior to encapsulation of the spacecraft in the payload portion of the shroud August 3. The spacecraft is to be moved to Complex 41 for mating with TC-7 August 5.

The second flight spacecraft arrived at Kennedy Space Center on May 23. After initial processing of the propulsion and mission modules at ESA-60A and Hangar AO respectively, they were moved to SAEF-2 during the second week in July. The spacecraft modules were mated during the fourth week of July. The nuclear electrical generator power source is to be installed and the spacecraft encapsulated in its shroud during the third week of August. If the first Voyager launch goes on schedule, the spacecraft will be moved to Complex 41 for mating with TC-6 August 23 in preparation for a launch scheduled for September 1.

Launch Operations

Launch will be directed from VIB, a 23-story structure containing nine million cubic feet of space. The Launch Control Area, consisting of three rooms, is the nerve center of the Titan-Centaur Complex. The VIB is located 5,900 meters (19,400 feet) from LC-41.

Press Site 3, the press viewing area for Titan III launches, is located southeast of the VIB and about 6,100 meters (20,000 feet) from LC-41.

TYPICAL VOYAGER LAUNCH SEQUENCE

Following is a sequence of selected launch vehicle and spacecraft events based on an August 20, 1977, launch and a Jupiter arrival date in mid-July, 1979.

The time of events presented in the Table depend on launch day--arrival day and trajectory. Events initiated after the parking orbit coast, due to coast time variance, may vary in real time as much as 5 minutes over the launch period for a particular launch day. The relative time of occurrence between events after the parking orbit coast, however, will remain the same. T-time is time from lift off, but includes two scheduled holds of 1 hour and 10 minutes duration. L-time is essentially real time from lift off and has no scheduled hold. I-time denotes time relative to propulsion module burnout (injection).

Count Time	Relative Time	Event	Comments
T-6:50:00	L-8:00:00	Unshort RTGs	S/C power on
T-0:00:00.2	L-0:00:00.2	Titan Stage 0 ignition	Titan solid boosters
T-0:00:00	L-0:00:00	Liftoff	
T+0:00:10		Vent RTGs	Pressure release device actuates approximately 6,100 m (20,000 ft.)
T+0:01:49		Stage 0 shutdown	
T+0:01:51		Stage 1 ignition	
T+0:02:02		Stage 0 separation	
T+0:04:20		Stage 1 shutdown	
T+0:04:21		Stage 1 separation Stage 2 ignition	
T+0:04:31		Centaur shroud jettison	
T+0:07:51		Stage 2 shutdown	
T+0:07:57		Stage 2 separation	
T+0:08:08		Centaur main engine start (MES 1)	
T+0:09:50		Centaur main engine cutoff (MECO 1) Begin parking orbit coast	
T+0:20:00	L+0:20:00	Minimum RTG power after venting	

Count Time	Relative Time	Event	Comments
T+0:40:00		Enter Earth shadow	Shadow entry can vary between T+0:37:30 and T+0:51:08 over the launch period
T+0:42:25		Centaur main engine start (MES-2)	MES 2 can vary between T+0:47:30 and T+0:56:30
T+0:48:08		Centaur main engine cutoff (earliest MECO 2)	MECO 2 can vary between T+0:53:30 and T+1:02:30 launch period
T+0:58:30		Start post MECO 2 coast	Post MECO 2 coast time is 185 seconds up through Sept. 12 launches and 85 seconds thereafter
T+1:00:11	I-0:02:09	Select telemetry modulation unit status	S-band high rate channel
T+1:00:11	I-0:02:09	Select flight data subsystem mode	High rate engineering data (1200 b.p.s.)
	I-0:01:04	Activate propulsion module batteries	CCS issues DC-4T commands
	I-0:01:02	Gyros to high rate mode	
	I-0:01:00	Spacecraft-Centaur separation	Separation occurs 15 sec. before propulsion module ignition.

Count Time	Relative Time	Event	Comments
	I-00:00:50	Thrust vector control engines in burn mode	100-pound-thrust engines enabled for pitch and yaw control; 5-lb. thrust engines for roll
	I-0:00:45	Start solid motor	Propulsion module ignition--timed from Centaur separation
T+1:02:19	I-0:00:00	Propulsion module burnout (mission module injection)	Propulsion module burnout injection may occur as early as 57.5 min. after launch or as late as 66 min. after launch throughout the launch period.
	I+0:00:05	Post burn mode/5-lb. engine control	100-lb. engines turned off
	I+0:00:15	Commanded turn	Commanded pitch turn of 114° at 2.88° per second
T+1:03:21	I+0:01:02	Release RTG boom	
	I+0:01:07	Release science boom	
T+1:05:04		Exit Earth shadow	Shadow exit varies between T+1:03:08 and T+1:14:50
	I+0:06:12	Booms deployed Slew scan platform	Slew to point at calibration target (Az q degrees, 26 min; El 109 degrees, 26 min

Count Time	Relative Time	Event	Comments
	I+0:11:12	Actuate propulsion module isolation valves	Seals off hydrazine line between mission and propulsion modules
	I+0:11:17	Jettison propulsion module	
	I+0:11:18	Attitude control status	All axes inertial; mission module engine control; gyros remain at high rate
	I+0:11:21	Select flight data subsystem mode	40 bps engineering data on downlink
	I+0:21:00	Select telemetry modulation unit status	S-band high rate data channel to allow general science to be on the downlink (7.2 k.b.p.s.)
	I+0:21:52	Plasma wave instrument	
	I+0:22:09	Low energy charged particle instrument on	
	I+0:23:28	Magnetometers on	
	I+0:27:00	Release magnetometer boom	
T+01:37:19	I+0:35:00	Magnetometer boom deployed	Latest deploy time

- more -

Count Time	Relative Time	Event	Comments
	I+0:35:00	Commanded turn to sun point on roll axis, then yaw axis	
T+2:07:00	I+1:05:00	Initiate sun acquisition	
	I+1:10:00	Sun acquired	Roll inertial mode
		Slew scan platform in elevation and azimuth	Slew platform to sweep instruments across Earth during star map
	I+1:10:09	Start LECP scan	Normal scan: fast stepping
	I+1:11:20	Planetary radio astronomy instrument on	
	I+:1:12:15	PRA/PWS antenna deploy motor on	
	I+1:22:15	Antennas deployed	
	I+1:27:15	Photopolarimeter on	
	I+1:29:40	Canopus star tracker 1 on	
	I+1:32:00	Star map commanded turn	One roll revolution to vicinity of Canopus
	I+2:30:54	Star map/commanded turn complete	
	I+2:45:00	Command turn to Canopus (roll)	Small turn to Canopus

- more -

Count Time	Relative Time	Event	Comments
		Canopus acquisition (Flyback and sweep)	Star acquisition should take less than 1 min; then celestial cruise automatic; gyros off
T+3:57:19	I+2:55:00	S-band radio transmitter to high power; tape recorder to ready mode	
T+4:06:06	I+3:03:41	Tape recorder state change	Playback launch data 33 k.b.p.s.
T+24 hours		Plasma science on	
T+36 hrs		Ultraviolet spectrometer on	
T+43 hrs		Release dust cover--infrared spectrometer and radiometer	
T+48 hrs		Cosmic ray science on	

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TRACKING AND DATA ACQUISITION

Tracking, commanding and obtaining data from the spacecraft are part of the mission assigned to the Jet Propulsion Laboratory (JPL), Pasadena, Calif. These tasks cover all phases of the flight, including telemetry from launch vehicle and spacecraft, metric data on both launch vehicle and Voyager, command signals to the spacecraft and delivery of data to the Mission Control and Computing Center (MCCC) at JPL.

The Tracking and Data System (TDS) will provide elements of the world-wide NASA JPL Deep Space Network (DSN), Air Force Eastern Test Range (AFETR), the NASA Spaceflight Tracking and Data Network (STDN) and the NASA Communications System (NASCOM).

During the launch phase of the mission, data acquisition will be accomplished through use of the near Earth facilities--the AFETR stations, downrange elements of the STDN, instrumented jet aircraft and a communications ship. Radar-metric data obtained immediately after liftoff and through the near Earth phase will be delivered to and computed at the AFETR Real time Computer system facility in Florida so that accurate predictions can be transmitted to Deep Space Network stations giving the locations of the spacecraft in the sky when they appear on the horizon.

Tracking and communications with the Voyagers from injection into Jupiter transfer trajectory until the end of the mission will be carried out by the Deep Space Network (DSN).

The DSN consists of nine deep space communications stations on three continents, a spacecraft monitoring station in Florida, the Network Operations Control Center in the MCCC at JPL and ground communications linking all locations.

DSN stations are located strategically around the Earth--at Goldstone, Calif.; Madrid, Spain; and at Canberra, Australia. Each location is equipped with a 64-m diameter (210 ft.) antenna station and two 26-m (85 ft.) antenna stations.

The three multi-station complexes are spaced at widely separated longitudes around the world so that spacecraft beyond Earth orbit--and, for the Voyager mission, the planets Jupiter and Saturn--are never out of view. The spacecraft monitoring equipment in the STDN station at Merritt Island, Fla., covers the prelaunch and launch phases of the mission. A simulated DSN station at JPL, called CTA-21, provides pre-launch compatibility support.

In addition to the giant antennas, each of the stations is equipped with transmitting, receiving, data handling and interstation communication equipment. The downlink includes supercooled lownoise amplifiers. The 64-m antenna stations in Spain and Australia have 100-kw transmitters. At Goldstone, the uplink signal can be radiated at up to 400 kw. Transmitter power at all six 26-m stations is 20 kw.

The downlink is transmitted from the spacecraft at S-band (2295 mHz) and X-band (8400 mHz) frequencies. The uplink operates at S-band (2113 mHz) only, carrying commands and ranging signals from ground stations to the spacecraft.

Only the 64-m antenna stations can receive the X-band signal and can receive at both frequencies simultaneously. The 64-m stations will provide continuous coverage during planetary operations and periodically during the cruise phase for maneuvers, spacecraft recorder playbacks and dual-frequency navigation sequences. A 26-m antenna subnet will provide continuous coverage--shared by the two spacecraft--throughout the mission.

Various data rates for each type of telemetered information are required by the changing length of the telecommunications link and the possible adverse weather effects at ground stations on reception of X-band radio signals.

Nerve center of the DSN is the Network Operations Control Center at JPL which provides for control and monitoring of DSN performance. All incoming data is validated at this point, while being simultaneously transferred to the computing facilities of the Mission Control and Computing Center for real time use by engineers and science investigators.

Ground communications facilities used by the DSN to link the global stations with the control center are part of a larger network, NASCOM, which connects all of NASA's stations around the world. Data from the spacecraft are transmitted over high speed circuits. Telemetry at rates up to and including 115.2 k.b.p.s. will be carried in real time on wideband lines from Goldstone and Madrid. The Canberra stations will send encounter data in real time at rates up to and including 44.8 k.b.p.s. Higher downlink rates will be recorded at the station and played back to MCCC at 44.8 k.b.p.s.

Simultaneously with the routing to the MCCC of the spacecraft telemetry, range and range rate information will be generated by the DSN and transmitted to the control center for spacecraft navigation. To achieve the desired maneuver and encounter accuracies, very precise navigation data is required. Navigation information includes S-X ranging, DRVID (differenced range versus integrated Doppler) and multi-station tracking cycles.

Commands are sent from the MCCC to one of the DSN stations where they are loaded into a command processing computer, automatically verified for accuracy and transmitted to the proper spacecraft at 16 bpsec. Commands may be aborted, if necessary. Manual control and entry of command data at the station is possible in the event of a failure in the high speed data line from the control center.

For all of NASA's unmanned missions in deep space, the DSN provides the tracking information on course and direction of the flight, velocity and range from Earth. It receives engineering and science telemetry and sends commands for spacecraft operations on a multi-mission basis.

Concurrent with the four-year or longer Voyager mission, the network is supporting the extended mission activities of the Viking Project with two Landers on Mars and two Orbiters circling the planet; maintaining post-Jupiter communications with Pioneers 10 and 11; and complementing West Germany's space communications facilities on two Helios Sun orbiting missions. The DSN also will support a Venus exploration mission by two Pioneer Venus spacecraft--a planetary orbiter and atmospheric probe--scheduled for launch in May and August, 1978, and planetary science activities beginning the following December.

All of NASA's networks are under the direction of the Office of Tracking and Data Acquisition. JPL manages the DSN. The STDN facilities and NASCOM are managed by the NASA Goddard Space Flight Center, Greenbelt, Md.

The Goldstone DSN stations are operated and maintained by JPL with the assistance of the Ford Aerospace and Communications Corp. The Canberra stations are operated by the Australian Department of Supply. The stations near Madrid are operated by the Spanish government's Instituto Nacional de Tecnica Aerospacial.

MISSION CONTROL AND COMPUTING CENTER

The Mission Control and Computing Center (MCCC) at the Jet Propulsion Laboratory is the focus of all Voyager Project flight operations. It is through the center's computer systems that data from the Voyagers pass, are processed and presented to the engineers and scientists for analysis. Through the extensive and varied displays of the computers in the MCCC, the flight analysts observe and control the many ground processing functions and the spacecraft.

The MCCC is housed in two JPL buildings containing its computer systems, communications and display equipment, photo processing lab and mission support areas. The various areas are outfitted to satisfy the diverse needs of the Voyager mission operations team--requirements of the mission controllers, spacecraft performance analysts and science investigators.

The MCCC contains several computer systems designed to receive the incoming Voyager data, process it in real time, display it and organize it for further processing and analysis. After the data have been received as radio signals by the Deep Space Network (DSN) stations located around the world, they are transmitted to Pasadena and into the MCCC computers, where the processing begins. Software developed by the MCCC, operating in these computers, performs the receiving, displaying and organizing functions. Computer programs generated by other elements of the Voyager Project further process the data.

Commands causing the spacecraft to maneuver, gather science data and perform other complex mission activities are introduced into the MCCC computers and communicated to a station of the DSN for transmission to the appropriate spacecraft.

The MCCC is composed of three major elements, each with its own computer system. They are the Mission Control and Computing Facility (MCCF), the General Purpose Computing Facility (GPCF) and the Mission Test and Computing Facility (MTCF).

The MCCF consists of three IBM 360-75 processors and supports the Voyager command, data records and tracking systems. The 360-75s provide the means through which commands are sent to the spacecraft. They also are used to process and display tracking and data and provide the data management capability to produce plots and printouts for the day to day determination of spacecraft operating conditions. The 360-75s also produce the final records of data for detailed analysis by the science community.

The GPCF, with three UNIVAC 1108 computers, supports the Voyager Project's navigation and mission sequence systems. The 1108s also are used to develop prediction programs and detailed spacecraft engineering performance analysis. Computer terminals located in the mission support area allow project analysts to execute their programs and obtain results displayed on TV monitors, or on various printers and plotters.

The MTCF provides telemetry data processing for the science and engineering information transmitted from the Voyagers. Within the MTCF are the telemetry system, imaging system and photo system. The telemetry system uses three strings of UNIVAC and Modcomp computers to receive, record, process and display the data as requested by analysts in the mission support areas. The imaging and photo systems produce the photographic products from data generated by Voyager's TV cameras. Pictures of Jupiter, Saturn and their moons will be analyzed by scientists housed in the mission support areas. Scientists will be provided both electronic and photographic displays.

MCCC, like the DSN, also supports the other flight missions, Viking, Pioneers 10 and 11, Helios and the upcoming Pioneer/Venus mission in 1978.

VOYAGER TEAM

NASA Headquarters

Office of Space Science

Dr. Noel W. Hinners	Associate Administrator for Space Science
Dr. Anthony J. Calio	Deputy Associate Administrator
Dr. S. Ichtiaque Rasool	Deputy Associate Administrator - Science
A. Thomas Young	Director, Lunar and Planetary Programs
Rodney A. Mills	Program Manager
Arthur Reetz, Jr.	Deputy Program Manager
Dr. Milton A. Mitz	Program Scientist
Earl W. Glahn	Flight Support Manager

Office of Tracking and Data Acquisition

Gerald M. Truszynski	Associate Administrator for Tracking and Data Acquisition
Charles A. Taylor	Director, Network Operations and Communication Programs
Arnold C. Belcher	Program Manager for DSN Operations
Frederick B. Bryant	Director, Network System Development Programs
Maurice E. Binkley	Director, DSN Systems

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Office of Space Flight

John F. Yardley	Associate Administrator for Space Flight
Joseph B. Mahon	Director, Expendable Launch Vehicles
Joseph E. McGolrick	Director, Small and Medium Launch Vehicles
B. C. Lam	Titan III Manager

NASA Jet Propulsion Laboratory

Dr. Bruce C. Murray	Director
Gen. Charles H. Terhune, Jr.	Deputy Director
Robert J. Parks	Assistant Director for Flight Projects
John R. Casani	Project Manager
Raymond L. Heacock	Spacecraft System Manager
Charles E. Kohlhase	Mission Analysis and Engineering Manager
James E. Long	Science Manager
Richard P. Laeser	Mission Operations System Manager
Esker K. Davis	Tracking and Data System Manager
James F. Scott	Mission Control and Computing Center Manager
Ronald F. Draper	Spacecraft System Engineer
William S. Shipley	Spacecraft Development Manager
William G. Fawcett	Science Instruments Manager
Michael Devirian	Chief of Mission Operations

California Institute of Technology

Dr. Edward C. Stone	Project Scientist

Lewis Research Center

Dr. Bruce T. Lundin	Director
Andrew J. Stofan	Director, Launch Vehicles
H. O. Slone	Launch Vehicle Systems Manager
Carl B. Wentworth	Chief, Program Integration Division
Gary D. Sagerman	Voyager Mission Analyst
Richard P. Geye	Voyager Mission Project Engineer
Richard A. Flage	Launch Vehicle Test Integration Engineer
Richard E. Orzechowski	TDS Support Engineer
Larry J. Ross	Chief, Vehicles Engineering Division
James E. Patterson	Associate Chief, Engineering Division
Frank L. Manning	TC-6 and TC-7 Vehicle Engineer

Kennedy Space Center

Lee R. Scherer	Director
Walter J. Kapryan	Director of Space Vehicle Operations
George F. Page	Director, Expendable Vehicles
John D. Gossett	Chief, Centaur Operations Division

Kennedy Space Center (cont'd.)

Creighton A. Terhune	Chief Engineer, Operations Division
Jack E. Baltar	Centaur Operations Branch
Donald C. Sheppard	Chief, Spacecraft and Support Operations Division
James E. Weir	Spacecraft Operations Branch
Floyd A. Curington	Voyager Project Engineer

Energy Research and Development Administration

Douglas C. Bauer	Director, Nuclear Research and Applications
Bernard J. Rock	Assistant Director for Space Applications
James J. Lombardo	Chief, Power Systems Branch
Thaddeus G. Dobry	Chief, Flight Safety Branch
Norman Thielke	Chief, Heat Source Branch
Alfred L. Mowery	Chief, Technical Support Branch

VOYAGER SUBCONTRACTORS

Following is a list of some key subcontractors who provided instruments, hardware and services for the Voyager project:

Algorex Data Corp. Syosset, N.Y.	Automated Design Support for Flight Data Subsystem
Boeing Co. Seattle, Wash.	Radiation Characterization of Parts and Materials
Fairchild Space & Electronics Co. Germantown, Md.	Temperature Control Louvers

Ford Aerospace & Communications Corp. Palo Alto, Calif.	S/X-Band Antenna Subsystem; Solid-State Amplifiers
Frequency Electronics, Inc. New Hyde Park, N.Y.	Ultra Stable Oscillators
General Electric Co. Space Division Philadelphia, Pa.	Radioisotope Thermoelectric Generators
General Electric Co. Utica, N.Y.	Computer Command Subsystem; Flight Control Processors
General Electric Co. Space Systems Organization Valley Forge, Pa.	Attitude Control and Articulation Subsystem
Hi-Shear Corp. Ordnance Division Torrance, Calif.	Pyrotechnic Squibs
Honeywell, Inc. Lexington, Mass.	Canopus Star Trackers
Hughes Aircraft Co. Aerospace Group Culver City, Calif.	Radiation Characterization of Parts and Materials
Lockheed Electronics Co. Industrial Technology Division Plainfield, N.J.	Data Storage Tape Transport
Martin Marietta Aerospace Denver, Colo.	Attitude Control Electronics; Propulsion Subsystem
Motorola, Inc. Government Electronics Div. Scottsdale, Ariz.	Modulation-Demodulation Subsystem; Radio Frequency Subsystem
Rocket Research Corp. Redmond, Wash.	Rocket Engine and Thruster Valve Assemblies
SCI Systems, Inc. Huntsville, Ala.	Computer Command Subsystem Memories

Teledyne Microelectronics Los Angeles, Calif.	Hybrid Memories for Flight Data Subsystem
Texas Instruments Dallas, Tex.	Data Storage Electronics
The Singer Co. Little Falls, N.J.	Dry Inertial Reference Units (Gyroscopes)
Thiokol Chemical Corp. Elkton Division Elkton, Md.	Solid Rocket Motor
Watkins-Johnson Co. Palo Alto, Calif.	S/X-Band Traveling Wave Tube Amplifiers
Xerox Corp. Electro-Optical Systems Pasadena, Calif.	Power Subsystem
Yardney Electronics Corp. Denver, Colo.	Flight and Test Battery Assemblies

Science Instruments

Massachusetts Institute of Technology Cambridge, Mass.	Plasma Subsystem
University of Colorado Boulder, Colo.	Photopolarimeter Subsystem
University of Iowa Iowa City, Iowa	Plasma Wave Subsystem
Xerox Corp. Electro-Optical Systems Pasadena, Calif.	Imaging Science (TV) Electronics
Kitt Peak National Observatory Tucson, Ariz.	Ultraviolet Spectrometer
Johns Hopkins University Applied Physics Laboratory Baltimore, Md.	Low-Energy Charged Particles Subsystem

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Goddard Space Flight Center Greenbelt, Md.	Magnetometers; Cosmic-Ray Subsystem
Texas Instruments Dallas, Tex.	Modified Infrared Interferometer, Spectrometer and Radiometer
Martin Marietta Aerospace Denver, Colo.	Planetary Radio Astronomy Subsystem
Astro Research Corp. Santa Barbara, Calif.	Magnetometer Boom; Planetary Radio Astronomy Antennas
TRW Defense and Space Systems Redondo Beach, Calif.	Ultraviolet Spectrometer Electronics
Matrix Corp. Acton, Mass.	Plasma Subsystem Electronics
General Electrodynamics Corp. Dallas, Tex.	TV Vidicons

CONVERSION TABLE

Multiply	By	To Get
Inches	2.54	Centimeters
Centimeters	0.3937	Inches
Feet	30.48	Centimeters
Centimeters	4.7244	Feet
Feet	0.3048	Meters
Meters	3.2808	Feet
Yards	0.9144	Meters
Meters	1.0936	Yards
Statute Miles	1.6093	Kilometers
Kilometers	0.6214	Miles
Feet Per Second	0.3048	Meters Per Second
Meters/Second	3.281	Feet/Second
Meters/Second	2.237	Statute Miles/Hour
Feet/Second	0.6818	Miles/Hour
Miles/Hour	1.6093	Kilometers/Hour
Kilometers/Hour	0.6214	Miles/Hour
Pounds	0.4563	Kilograms
Kilograms	2.2046	Pounds

To convert Fahrenheit to Celsius (Centigrade), subtract 32 and multiply by 5/9.

To convert Celsius to Fahrenheit, multiply by 9/5 and add 32.

To convert Celsius to Kelvin, add 273.

To convert Kelvin to Celsius, subtract 273.

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